Marine Macrobenthic Colonization of Mine Tailings in Rupert Inlet, British Columbia.

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No one successional sequence of taxa or ecological groups was evident in artificial substrate communities. Successional patterns varied seasonally and with substrate type. Random immigration patterns probably also contributed to the variation in succession.

Tailing and control substrates were colonized by similar taxonomic assemblages. However, a tailing substrate retarded the rate of community development. The component of tailings responsible for this has not been identified. Depressed colonization rated in tailings may cause the tailing community to equilibrate at a lower species number than controls. Alternatively, tailings may reach the same equilibrium as controls. However, the time to equilibrium in tailings will be longer than in controls.

Macrobenthic communities in Rupert Inlet close to the tailngs outfall or in the main path of the turbidity current are in very early stages of succession. Continual disturbance form tailings discharge is probably responsible for this.

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The practical implications of an ecological system is just this: we can never touch merely one thing....Living things are all a part of a "web of life"- the phrase is Darwin's- and we cannot touch a single species without tugging at relational strands extending in all directions.

G. Hardin

INTRODUCTION

I. Marine Benthic Colonization

The colonization and development of a community[1] can be altered by man-made and natural changes to the physical and chemical environment. An alteration in community development is effected through changes in the rate of species colonization or extinction (MacArthur and Wilson, 1963, 1967), or by changes in the identity of the species colonizing or leaving the community. Species colonization and extinction are here defined, as the number of new species arriving per unit time, and the number of species leaving per unit time.

Community development in most habitats is poorly described and understood. Consequently, an examination of a developing community's response to physical or chemical change must often be preceded by a description of community development in the habitat of interest.

Macrobenthic colonization of soft marine substrates has been investigated in many locations (Dauer and Simon, 1976a; McCall, 1977,1978; Bonsdorff, 1980; Arntz and Rumohr, 1982; Zajac and Whitlatch, 1982; Winieki and Burrell, 1985). Among these studies there is considerable variation in the reported sequence of

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[1] Community is defined in this thesis following Mills (1969) as "a group of organisms occurring in a particular environment, presumably interacting with each other and with the environment, and separable by means of ecological survey from other groups."

taxa and colonization rate (rate of increase in species number). This is not surprising, as the investigations differ in their geographic location, ambient environment, and sampling technique. McCall (1977, 1978) suggests that a universal pattern of macrobenthic colonization may emerge, if species are categorized according to life history rather than taxonomic characteristics. On this basis McCall (1977, 1978) proposes that soft substrates are initially colonized by opportunistic species, typified by rapid dispersal, reproduction, and growth. These eventually give way to equilibrium species, characterized by slow dispersal, reproduction, and growth. While such a sequence may occur, data to substantiate this are currently insufficient. In particular, information on life histories of many benthic organisms is needed before they can be classified into such a scheme. Clearly, macrobenthic colonization patterns vary and no universal trend has yet become evident. Therefore, macrobenthic colonization in the habitat to be studied must be described, prior to an examination of how abiotic factors affect this colonization process.

Most investigations describing macrobenthic colonization have followed a colonization sequence begining at only one point during the year. However, community structure, larval settlement, and colonization fluctuate seasonally in many benthic habitats (Moore, 1978; Dean and Hurd, 1980; Arntz and Rumohr, 1982; Cameron and Rumrill, 1982; Mahoney and Livingston, 1982; Zajac and Whitlatch, 1982; Day, 1984; Winiecki and Burrell, 1985) To establish general patterns in benthic community development, or even in the description of the colonization of one habitat, seasonal variation should be documented.

II. Marine Mine Tailing Disposal

The disposal of pollutants into marine environments is a widespread and by no means recent phenomenon. Despite this, few authors have examined effects of pollutants on benthic colonization (Dean and Haskin, 1964; Cory and Nauman, 1970; Reish, 1971; Rosenberg 1972, 1973, 1976). Rather, colonization research has focused on the effects of natural factors. (Schoener, 1974; Dauer and Simon, 1976b; Osman, 1977; Richter and Sarnthein, 1977; Dean and Hurd, 1980). Concurrently, biological marine pollution assessment has centred on delineating impacts to individual species and community structure during discharge (Grassle and Grassle, 1974; Godfrey, 1978; Gray, 1979; Pearson *et al.*, 1982; Houston *et al.*, 1983; Phelps *et al.*, 1983). However, to fully assess a pollutant's biological impacts, knowledge must be available, not only on how existing communities are affected, but also on how they recover once pollution ceases. In many instances recovery occurs through colonization. Information on colonization is, therefore, essential in the process of making informed decisions on the extent and types of pollutants permitted to be released to marine environments.

In contrast to many industrial operations, mines locate in and perturb areas for relatively short time periods, as mining and processing usually cease when surrounding ore bodies are exhausted. Thus, knowledge of post-mining recovery processes is in high demand due to the frequency of mine closures. In terrestrial systems, disturbances caused by mining activities have initiated extensive research into colonization processes to provide information for development of terrestrial reclamation and mitigation practices (Wali, 1975; Thames, 1977; Hutson, 1980;

Meidinger, 1981). Marine investigations into mining related disturbances have not advanced to this stage. Instead, like the majority of marine pollution assessments, they primarily involve description of impacts during mining operations, with little attention directed to post-operational effects. An exception is the work of Kathman *et al.* (1984), who examined benthic communities in a fiord twelve months after a molybdenum mine ceased discharging into the water body.

Historically, marine systems have received little of the tailings generated by mines, as the majority of mines are inland and dump wastes to terrestrial or fresh water environments. However, presently there are a growing number of coastal mines that discharge tailings to marine environments (Pedersen, 1985). Marine disposal presents advantages to coastal mines, as it is often cheaper than land impoundment, circumvents problems of ground water contamination, and avoids dangerous tailing pile slumps induced by high rainfall or earthquakes (Pedersen, 1984).

Currently, a submarine tailings disposal system discharging into the aphotic zone is the preferred technique for marine tailings release. This method minimizes impact on primary productivity in the photic zone. In the majority of situations, submarine release will create an area of unstable bottom conditions, resulting from high sedimentation rates and localized build-up and subsequent slumping of tailing piles (Hay, 1981, 1982; Island Copper, 1977-1984). Thus, present tailing disposal practices primarily affect benthic communities.

The mine involved in this study, Island Copper Mine (1977-1985), reports reduction in the number of benthic species, and changes to community structure in areas of high tailing deposition and unstable substrate. As distance from the tailing outfall increases, impact to benthic communities decreases, probably in response to a higher degree of substrate stability and lower sedimentation rates. Tailings may also change benthic communities by altering physical and chemical sediment parameters, or by decreasing water depth over the sediment. However, the importance of these factors is uncertain, as mechanisms through which benthic communities are affected by tailings have not been fully elucidated.

The above summary illustrates that while impacts to benthic communities during tailing discharge have been characterized, recovery processes once discharge ceases remain relatively undescribed. Upon cessation of tailing release, impact to resident benthic communities will primarily be caused by the presence of a tailing substrate and its effect on water quality. To provide essential information on community recovery post-discharge, it is necessary for marine research to follow the terrestrial example, by investigating marine colonization processes to determine how mine tailing disposal affects colonization. Such studies may decrease impact by providing fundamental knowledge for development of marine reclamation and mitigation procedures.

III. Artificial Substrates

Methodological approaches employed in colonization studies have been either observational or experimental. *In situ* examination of naturally occurring colonization is preferable, but is only possible after disturbances denude large patches in a habitat or when new space is created. Such situations are quite rare. To overcome this two experimental techniques have been developed:

1) a site is cleared of organisms and colonization monitored (Bokenham and Stephenson, 1938; Fahey and Doty, 1949; Wilson and Simberloff, 1969).
2) an artificial substrate is introduced into a region and colonization observed (Cairns *et al.*, 1969; Fager, 1971; Goddard *et al.*, 1975; Goren, 1979; Hudon and Bourget, 1981).

In subtidal environments the first method is generally not feasible; thus use of artificial substrates has become the most common subtidal experimental technique. Typically, artificial substrates have been constructed of hard materials formed into plates or other solid shapes. These have provided information on hard substrate colonization, but give little insight into soft bottom processes.

As it is only recently that soft sediment artificial substrates have been designed and tested, studies on subtidal soft artificial substrate colonization are few. McCall (1977, 1978), Grassle (1977), Desbruyères *et al.* (1980), and Levin and Smith (1984) used soft artificial substrates to describe benthic colonization of sediments. Soft artificial substrates have been employed by Richter and Sarnthein (1977) to examine effects of sediment type on molluscan colonization, by Arntz and Rumohr (1982) and Winiecki and Burrell (1985) to assess importance of seasonal variation in benthic colonization, and by Watzin (1983) to observe effects of meiofauna on settling macrofauna. The last four studies demonstrate the applicability of artificial substrate methodology to investigations into the effects of changes in physical, chemical, and biological parameters on soft bottom benthic colonization. To date, however, this methodology has not been widely adopted.

IV. Objectives

The present study of macrobenthic colonization in Rupert Inlet, B.C. was initiated as a preliminary step towards describing community recovery once mine tailing discharge has terminated. This objective consists of two parts:

1) to describe macrobenthic colonization of mine tailings and a control substrate in Rupert Inlet, and to document seasonal variation in this colonization;
2) to determine if a tailing substrate affected macrobenthic colonization, and if effects were evident, to attempt to identify the season in which colonization is most susceptible to perturbations from tailing discharge.

Bottom conditions in much of Rupert Inlet are extremely unstable due to continuous marine release of tailings by Island Copper - Utah Mines. This instability precludes study of naturally occurring colonization on the mine tailings. Therefore, artificial substrates were used to examine tailing colonization in Rupert Inlet.

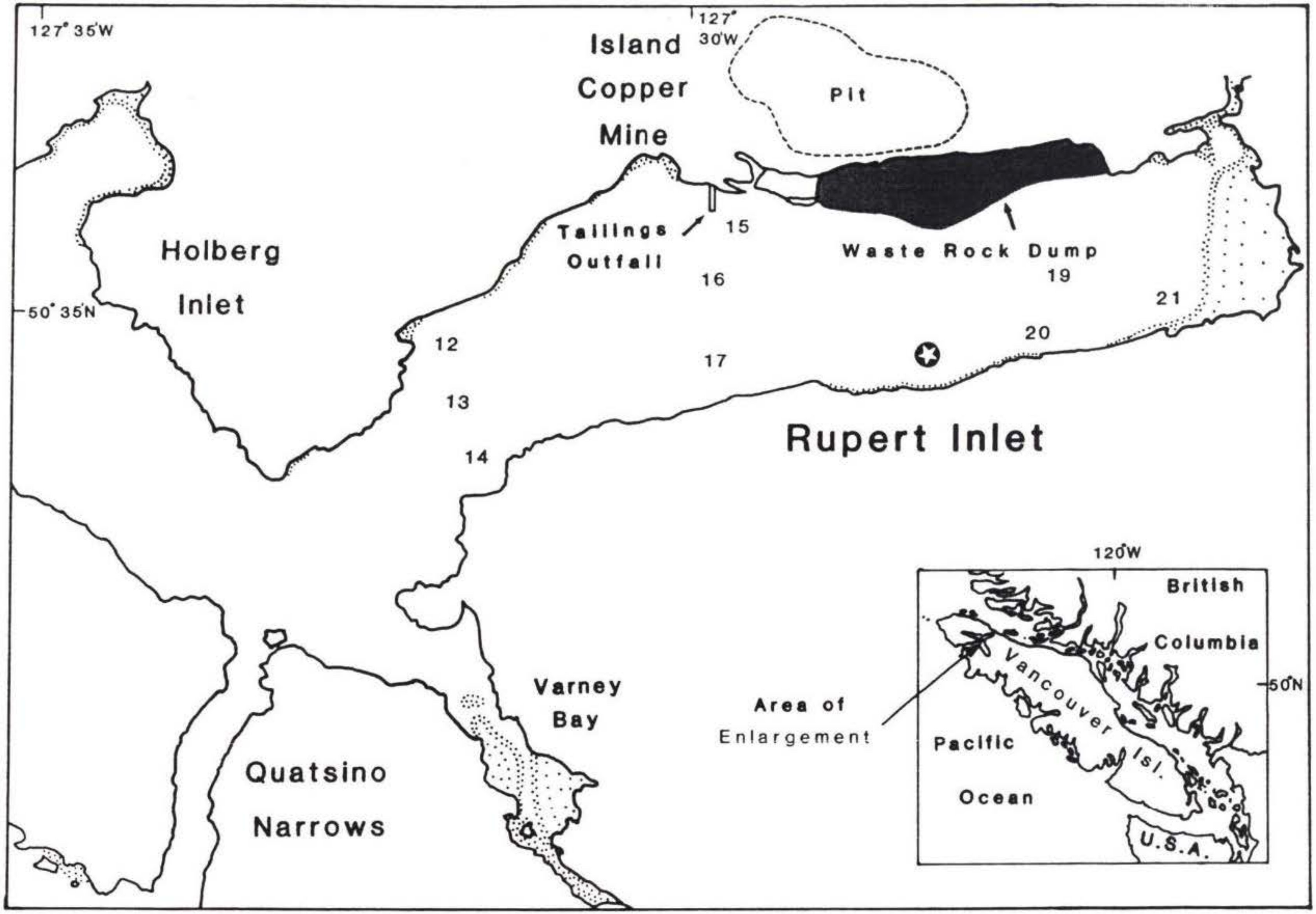
STUDY SITE DESCRIPTION

Rupert Inlet is a deep fiord located near the northern tip of Vancouver Island, British Columbia at 50°35'N and 127°30'W (Fig. 1). Its length is 10.2 km, average width 1.8 km and mean depth 110 m (Pickard, 1963). Artificial substrate experiments were situated near the southern shore of the fiord (Fig. 1). The inlet forms a continuous basin with Holberg Inlet. Opening to the sea is through Quatsino Narrows to Quatsino Sound. A sill, 18 m deep, lies at the northern end of the narrows. Principal freshwater input is from the Marble River, which enters through Varney Bay near the junction of the narrows and Rupert Inlet (Drinkwater and Osborne, 1975). Despite the presence of a sill, temperature, salinity, and dissolved oxygen display marked vertical uniformity (Drinkwater and Osborne, 1975). Drinkwater and Osborne (1975) attribute this to rapid tidal currents during flood tide entraining dense water from Quatsino Narrows. This water is then mixed with less dense layers in the narrows. Upon entering Rupert Inlet water is forced below the Marble River's freshwater lens; thus Rupert Inlet continually experiences some degree of deep water renewal.

Since October 1971 Island Copper - Utah Mines has been discharging tailings into Rupert Inlet. The copper and molybdenum mine is located on the north shore of the fiord. In 1984 the rate of release was approximately 40,000 tons per day, through a submarine outfall situated offshore from the mine at 50 m depth. Upon

Figure 1: Rupert Inlet and surrounding area.

Star shows location of artificial substrate experiments. Numbers indicate Island Copper Mine's benthic sampling stations 12-21.


127° 35'W
Island
Copper
Mine
127° 30'W
Pit
Holberg
Inlet
50° 35'N
Tailings
Outfall
15
Waste Rock Dump
16
19
21
12
20
17
13
Rupert Inlet
14
120°W
British
Columbia
50°N
Vancouver Isl.
Varney
Bay
Area of
Enlargement
Pacific
Ocean
U.S.A.
Quatsino
Narrows

discharge tailings form a turbidity current that moves along the bottom of Rupert Inlet. Hay (1981, 1982) and Island Copper (1977-1985) have demonstrated that the position of this current is not static or predictable, rather it meanders with time. This dynamic behavior of the tailing current creates constantly changing patterns of sedimentation and erosion on the bottom of Rupert Inlet. Tailings also collect in particular areas. These tailing piles periodically slump, creating localized turbidity currents (Hay, 1981, 1982).

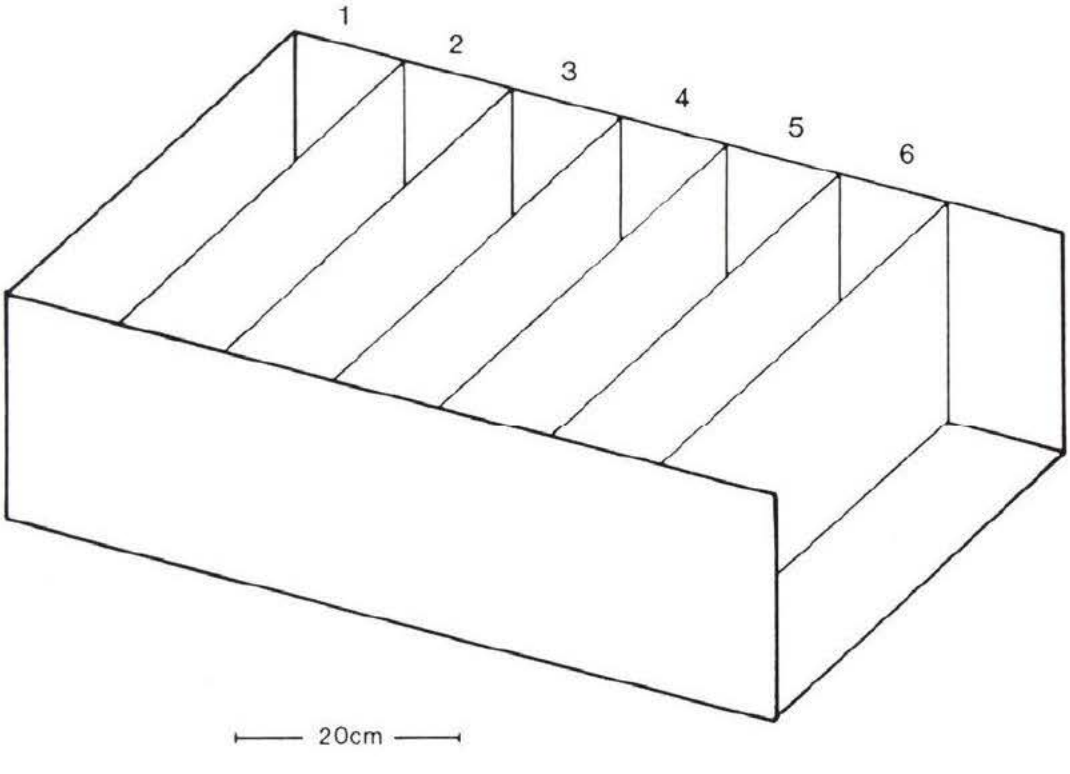
MATERIALS AND METHODS

I. Field Methods

An artificial substrate container was designed consisting of a 0.25 m^2 plywood box (0.71 m long, 0.35 m wide, 0.20 m deep) coated in polyester resin (Fig. 2). The boxes had only three sides, allowing lateral benthic immigration via the open end. A cylindrical sediment trap (8 cm diameter, 15 cm deep) attached to the outer wall of each box measured sedimentation rates. Containers were filled to a depth of 10 cm with one of two substrates. Tailings collected from the copper final tailings pipe in the mill acted as the experimental substrate. Tailings were collected immediately prior to use. The control substrate was quarried-marble sand with a grain size approximating that of the tailings.

Artificial substrate experiments were carried out near the south shore of Rupert Inlet (Fig. 1), where sedimentation from the tailings outfall was low and the sea floor was relatively level. Once every two months, for ten months commencing in August 1982, experimental units consisting of two tailing and two control artificial substrates were placed on the bottom of Rupert Inlet at a depth of 12-13 m. Units were left in place for 2, 4, 8, and 12 months. In July 1982 an additional experimental unit was started and exposed for one month. Figure 3 shows the type and number of experimental units initiated in each sampling month. Placement and retrieval operations were accomplished using Island Cop-

Figure 2: Artificial substrate container showing the stratified random sampling design.


1
2
3
4
5
6
20cm

per's research boat the Mac I. All artificial substrates were given a code which will be used through the text. Table 1 lists artificial substrates and their designated codes.

Prior to placement sediment was frozen in containers to prevent substrate loss while lowering boxes through the water column. Approximately 9 L of fresh water was mixed with the marble sand to allow freezing. Tailings required no additions as they contained fresh water.

At the sampling site seven metal weights were positioned on the bottom in a line parallel to shore. Buoys were attached to the weights to enable relocation. One buoy and weight marked the location of one experimental unit. Boxes were placed around weights with open ends facing shore to minimize and standardize current effects.

Placement was accomplished by attaching a box to a winched cable and guiding it through the water column with SCUBA divers to ensure proper positioning. For retrieval divers secured lids on boxes and sediment traps to minimize substrate loss during recovery. Boxes were then winched to the surface.

On several occasions collection of boxes was not possible as high winds and waves had caused the movement or disappearance of marker buoys. This, coupled with extremely high turbidity, made some containers impossible to relocate. Table 1 lists boxes lost throughout the field programme.

Upon retrieval, artificial substrates were cored using stratified random sampling. Boxes were divided into seven 10 cm strata parallel to the open ends (Fig.

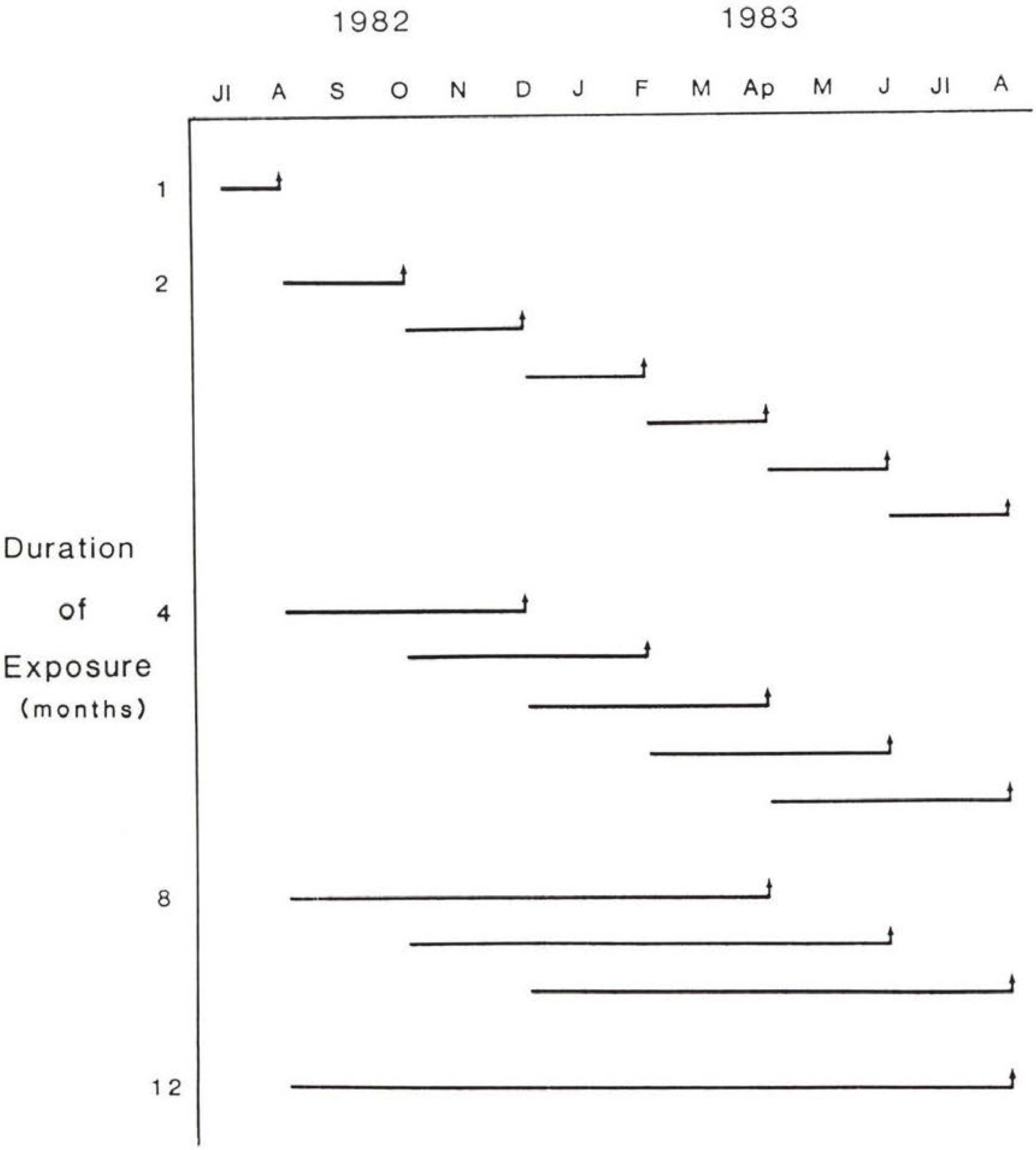
Table 1: Artificial substrate codes.

(*): artificial substrates not recovered. Pooled replicates have no replicate designation (a or b) in their code.

Substrate type	Exposure length (months)	Date initiated	Date retrieved	Replicate	Code
Tailings	1	July	Aug.	a	T1J1-A(a)
Tailings	1	July	Aug.	b	T1J1-A(b)
Control	1	July	Aug.	a	C1J1-A(a)
Control	1	July	Aug.	b	C1J1-A(b)
Tailings	2	Aug.	Oct.	a	T2A-O(a)
Tailings	2	Aug.	Oct.	b	T2A-O(b)
Control	2	Aug.	Oct.	a	C2A-O(a)
Control	2	Aug.	Oct.	b	C2A-O(b)
Tailings	2	Oct.	Dec.	a	T2O-D(a)
Tailings	2	Oct.	Dec.	b	T2O-D(b)
Control	2	Oct.	Dec.	a	C2O-D(a)*
Control	2	Oct.	Dec.	b	C2O-D(b)*
Tailings	2	Dec.	Feb.	a	T2D-F(a)
Tailings	2	Dec.	Feb.	b	T2D-F(b)
Control	2	Dec.	Feb.	a	C2D-F(a)
Control	2	Dec.	Feb.	b	C2D-F(b)
Tailings	2	Feb.	April	a	T2F-Ap(a)
Tailings	2	Feb.	April	b	T2F-Ap(a)
Control	2	Feb.	April	a	C2F-Ap(a)
Control	2	Feb.	April	b	C2F-Ap(b)
Tailings	2	April	June	a	T2Ap-J(a)
Tailings	2	April	June	b	T2Ap-J(b)
Control	2	April	June	a	C2Ap-J(a)
Control	2	April	June	b	C2Ap-J(b)
Tailings	2	June	Aug.	a	T2J-A(a)
Tailings	2	June	Aug.	b	T2J-A(b)
Control	2	June	Aug.	a	C2J-A(a)
Control	2	June	Aug.	b	C2J-A(b)
Tailings	4	Aug.	Dec.	a	T4A-D(a)
Tailings	4	Aug.	Dec.	b	T4A-D(b)
Control	4	Aug.	Dec.	a	C4A-D(a)
Control	4	Aug.	Dec.	b	C4A-D(b)*
Tailings	4	Oct.	Feb.	a	T4O-F(a)*
Tailings	4	Oct.	Feb.	b	T4O-F(b)*
Control	4	Oct.	Feb.	a	C4O-F(a)*
Control	4	Oct.	Feb.	b	C4O-F(b)*
Tailings	4	Dec.	April	a	T4D-Ap(a)
Tailings	4	Dec.	April	b	T4D-Ap(b)
Control	4	Dec.	April	a	C4D-Ap(a)
Control	4	Dec.	April	b	C4D-Ap(b)
Tailings	4	Feb.	June	a	T4F-J(a)
Tailings	4	Feb.	June	b	T4F-J(b)
Control	4	Feb.	June	a	C4F-J(a)
Control	4	Feb.	June	b	C4F-J(b)
Tailings	4	April	Aug.	a	T4Ap-A(a)
Tailings	4	April	Aug.	b	T4Ap-A(b)
Control	4	April	Aug.	a	C4Ap-A(a)
Control	4	April	Aug.	b	C4Ap-A(b)
Tailings	8	Aug.	April	a	T8A-Ap(a)
Tailings	8	Aug.	April	b	T8A-Ap(b)
Control	8	Aug.	April	a	C8A-Ap(a)*
Control	8	Aug.	April	b	C8A-Ap(b)
Tailings	8	Oct.	June	a	T8O-J(a)
Tailings	8	Oct.	June	b	T8O-J(b)*
Control	8	Oct.	June	a	C8O-J(a)
Control	8	Oct.	June	b	C80-J(b)*
Tailings	8	Dec.	Aug.	a	T8D-A(a)*
Tailings	8	Dec.	Aug.	b	T8D-A(b)*
Control	8	Dec.	Aug.	a	C8D-A(a)*
Control	8	Dec.	Aug.	b	C8D-A(b)*
Tailings	12	Aug.	Aug.	a	T12A-A(a)*
Tailings	12	Aug.	Aug.	b	T12A-A(b)
Control	12	Aug.	Aug.	a	C12A-A(a)*
Control	12	Aug.	Aug.	b	C12A-A(a)*

Figure 3: Schedule of artificial substrate placement and retrieval.

Each line represents one experimental unit (two tailing and two control artificial substrates). Arrows indicate month of retrieval.



Dates of Placement and Retrieval of Artificial Substrates

(months)

2). The 10 cm adjacent to the open end was not sampled as substrate slumping caused sediment loss. Two random 8 cm diameter cores were taken in each remaining 10 cm stratum. Paired cores were pooled and placed in a bucket of sea water. Buckets were gently rocked to break up cores, causing only minimal damage to organisms. The resulting slurry was slowly washed through a 0.5 mm sieve. Material retained was preserved in 10% buffered formalin and stored in 70% ethanol. Samples were collected from each box for grain size analysis both before and after exposure. Four of these samples were also used for heavy metal analysis. The contents from the sediment trap on T8A-Ap was retained for heavy metal analysis. The depth of substrate in boxes and sediment traps was measured.

II. Laboratory Methods

Each core sample was sorted twice under a binocular dissecting scope to separate organisms from debris. All specimens were identified to the lowest taxonomic level possible and counted, with the exception of foraminiferans. Foraminiferans were ignored as it was extremely difficult to determine whether they were inhabiting boxes or were empty tests deposited by currents or sedimentation (B. Cameron, Institute of Ocean Sciences, Sidney, B.C., pers. comm.).

As all organisms could not be identified to species level, taxa containing incomplete identifications were merged until a category was reached in which all members could be placed with certainty. For example, if a genus contained some individuals that had not been identified to species level, all individuals of the genus were grouped together at the generic level and treated as one taxon. The resulting taxonomic groupings (Appendix 1) were used for analysis.

Taxonomic identifications were based upon the following literature: Polychaeta - Banse and Hobson (1974), Hobson and Banse (1981), Fauchald (1977), Hartman (1968, 1969); Mollusca - Keen and Coan (1974), Abbot (1974); other taxa - Kozloff (1974). Amphipods were identified by P. Shaw, University of British Columbia, Vancouver and verified by E. Bousfield, National Museum of Natural Sciences (N.M.N.S.), Ottawa. Polychaete and mollusc identifications were verified by experts in the respective fields: Polychaeta - J. Fournier, N.M.N.S., Ottawa; Mollusca - M. Smith, N.M.N.S., Ottawa. Representative specimens of all species of polychaetes and molluscs have been deposited with the National Museum of Natural Sciences, Ottawa, Ontario, Canada.

Sediment grain size and degree of sorting were analysed by dry sieving and hydrometry (Bouyoucos, 1951). The pre- and post-exposure pH of tailings and marble sand was determined on two occasions by mixing duplicate samples of each sediment type with an equal amount of sea water and monitoring the pH over 24 hours. Sediment heavy metal content was analysed by R. Fyles, chemist, Utah Mines (see appendix 2 for methods of analysis).

III. Community Analysis

A. Uni- and Bivariate

For statistical analysis, the number of individuals and taxa in artificial substrates were calculated by pooling replicate containers and taking means and confidence intervals of the resulting twelve samples. The 0.05 level of significance was used for all statistical tests. Spearmans rank correlation analysis was used for all correlations as not all data met assumptions of normality.

Values used for the analysis of major taxonomic groups, polychaete feeding guilds, abundant species, and diversity were calculated by summing core values to obtain a box total. A mean for each replicate set was then calculated. Mean values were visually analysed for trends. For all analyses when one replicate of a pair was lost the numbers reported were derived from the remaining box.

Diversity was calculated using the Shannon-Wiener index (H') (Shannon and Weaver, 1949):

$$H' = \sum_{i=1}^{s} pi \ \ln(pi)$$

where s is the total number of species and p is the proportion of species i in the sample. H' was selected as it enjoys the greatest use of any diversity measure in aquatic ecology (Washington, 1984); thus rendering values from this study comparable with as many other reports as possible. Further, Washington (1984) states that despite its dubious value H' should not be immediately abandoned until other measures with better theoretical foundation or more biological relevance have been extensively tested.

B. Multivariate

Univariate analysis requires that samples be described in one dimension, i.e, by one number. Quantitative information gathered on species assemblages is generally multidimensional. It is usual to collect data on at least the number of species, species composition, and number of individuals per species (Bloom, 1980). Clearly, it is impossible to reduce this data to one dimension without a substantial loss of information. To elucidate patterns in these three parameters simultaneously, data were subjected to multivariate analysis.

The 12 cores from each artificial substrate container were pooled to produce species composition and species abundances per container. To reduce noise, replicates were analysed as one sample by taking means of species abundances between replicate pairs. Again, when one replicate was lost data from the remaining box was used.

The resulting sample by species matrix was subjected to a series of Non-Centred Principal Components Analyses (PCA), using the Cornell ecological computer program package ORDIFLEX (Gauch, 1977). An ordination technique was chosen because community structure and composition change continuously during colonization and succession, rather than moving through a series of discrete stages, which selection of a clustering technique would imply (Noy-Meir and Whittaker, 1977). More elaborate ordination methods were not used as PCA provided an adequate description of the data and proved superior to Reciprocal Averaging (RA) and Detrend Correspondents Analysis (DCA) in separating samples in space.

Non-centred PCA was employed in preference to centred as it produced a more effective summary of community variation. In all ordination analyses, the first three non-centred PCA axes accounted for a larger proportion of total variation than did corresponding centred axes. Further, non-centring allowed preservation of absolute occurrences and co-occurrences of species, and facilitated assessment of the number and sharpness of discontinuities in the data (Noy-Meir, 1973).

Ordinations of artificial substrate species assemblages use the dissimilarity measure Euclidian Distance (ED)(Gauch, 1982):

$$ED_{jk} = \left[\sum_{i=1}^{I} (A_{ij} - A_{ik})^2 \right]^{1/2}$$

where I is the total number of species, and A_{ij}, A_{ik} are the abundances of species i in samples j and k. Selection of this index was based on its consideration of both species occurrences and number of individuals per species.

Artificial substrate data were ordinated with Island Copper's 1982-83 benthic data from stations 12 - 21 in Rupert Inlet (Island Copper, 1983, 1984) using non-centred PCA. As the mine's sampling techniques differed in many respects from those of this study, species abundances were not comparable, and therefore only species presence or absence were used for ordination.

RESULTS

I. Physical and Chemical Analysis of Artificial Substrates

A. Sediment Particle Size

Median particle diameter of tailings used as artificial substrate was 0.046 ±0.022 mm (SD). Control substrate had a uniform median diameter of 0.097 mm. Generally both sediments were well sorted (ie. sorting coefficient <2.5 (Ellis, 1977)). Changes in sediment median grain size and degree of sorting from pre- to post-exposure were small (Appendix 3). Tailing substrates showed a mean change in median diameter of 0.003 ±0.006 mm (SD), while mean change in control boxes was 0.008 ±0.026 mm (SD) (Appendix 3). No discernable pattern is evident in the direction of particle size shift, as both increases and decreases were recorded.

B. pH

Substrate pH in sea-water was determined to establish if control sediment (marble sand) differed from the tailing substrate. Initial pH of control (8.0) and tailings (7.9) substrates were similar (maximum difference of pH 0.1) and approximated that of untreated sea-water, even after 48 hours (Appendix 4).

C. Substrate Depth and Sedimentation Rate

An average decrease in substrate depth of 1.8 ±1.0 cm (SD) occurred in containers during exposure. Mean sedimentation received by 4, 8, and 12 month containers was 1.0 ±0.8 cm (SD). Sedimentation into 2 month boxes was too low to measure. The maximum sediment accumulation was 3.0 cm, and was recorded in T12A-A and T4F-J. Boxes appeared to be both losing and receiving particles. The amount of sediment received and substrate depth after exposure are tabulated in appendix 5.

D. Heavy Metal Analysis

The contents of one sediment trap, exposed for eight months, were analysed for heavy metals. Heavy metal concentrations in the sediment trap were much higher than initial levels in control substrate, and differed from those measured for 8 month tailing boxes (Table 2). Over an eight month period heavy metal levels in control containers were elevated. Levels in tailing substrates may also have changed over time, however data to substantiate this are not available. Despite the temporal increase in heavy metal content of controls, 8 and 12 month tailing containers had much higher levels than 8 month controls (Table 2).

Table 2: Heavy metal concentrations in sediment trap and artificial substrates.

HM: heavy metal. (-): missing value. See table 1 for artificial substrate codes.

Heavy Metal Concentration (ppm)

HM	Sediment Trap	Marble Sand	Marble Sand Post-Exposure		Tailings Post-Exposure	
	T8A-Ap(a)	Pre-Exposure	C8A-Ap(b)	C8O-J(a)	T8A-Ap(a)	T12A-A(b)
Cu	290.0	5.4	26.0	26.0	1700	1500
Mo	24.0	2.0	3.5	3.3	71	120
Cd	<0.2	<0.2	0.3	0.3	1.0	0.9
Cr	59.0	2.8	5.5	5.3	24.0	21.0
Co	17.0	3.8	<2.0	<2.0	9.2	9.3
Fe	29500	270	1980	1750	37100	36100
Pb	40	21	18	18	29	22
Mn	900	41	77	83	670	530
Ni	26.0	9.8	5.7	5.4	22.0	19.0
Zn	160.0	7.4	12.0	10.0	250.0	210.0
As	-	-	0.3	0.5	17.0	16.0
Hg	0.14	-	0.3	0.2	0.7	0.1

II. Method of Recruitment - Adult or Larval

Artificial substrates were cored using stratified random sampling to determine if distribution of individuals and number of taxa, from open to closed ends of containers, was uniform. Significantly higher numbers near the open end would indicate lateral migration of adult organisms into boxes. Initially, information from all containers was pooled for each of the six strata sampled. One-way analysis of variance (ANOVA) on the pooled data demonstrated no significant differences from open to closed ends of boxes for either number of individuals or taxa (Table 3).

To detect temporal patterns in adult migration that the overall analysis would have missed, data were divided into subsets based on experimental length. Four subsets resulted: 1, 2, 4, and 8 month boxes. No significant differences in distribution of individuals or number of taxa were found for any of the subsets (one-way ANOVA) (Table 3).

Table 3: Probability values from one-way ANOVAs comparing (1) the number of individuals, and (2) the number of taxa between strata in artificial substrates.

Artificial Substrates Compared	df	Number of Individuals	Number of Taxa
All substrates	281	0.29	0.47
1 month substrates	23	0.90	0.86
2 month substrates	131	0.35	0.34
4 month substrates	90	0.79	0.67
8 month substrates	29	0.96	0.91

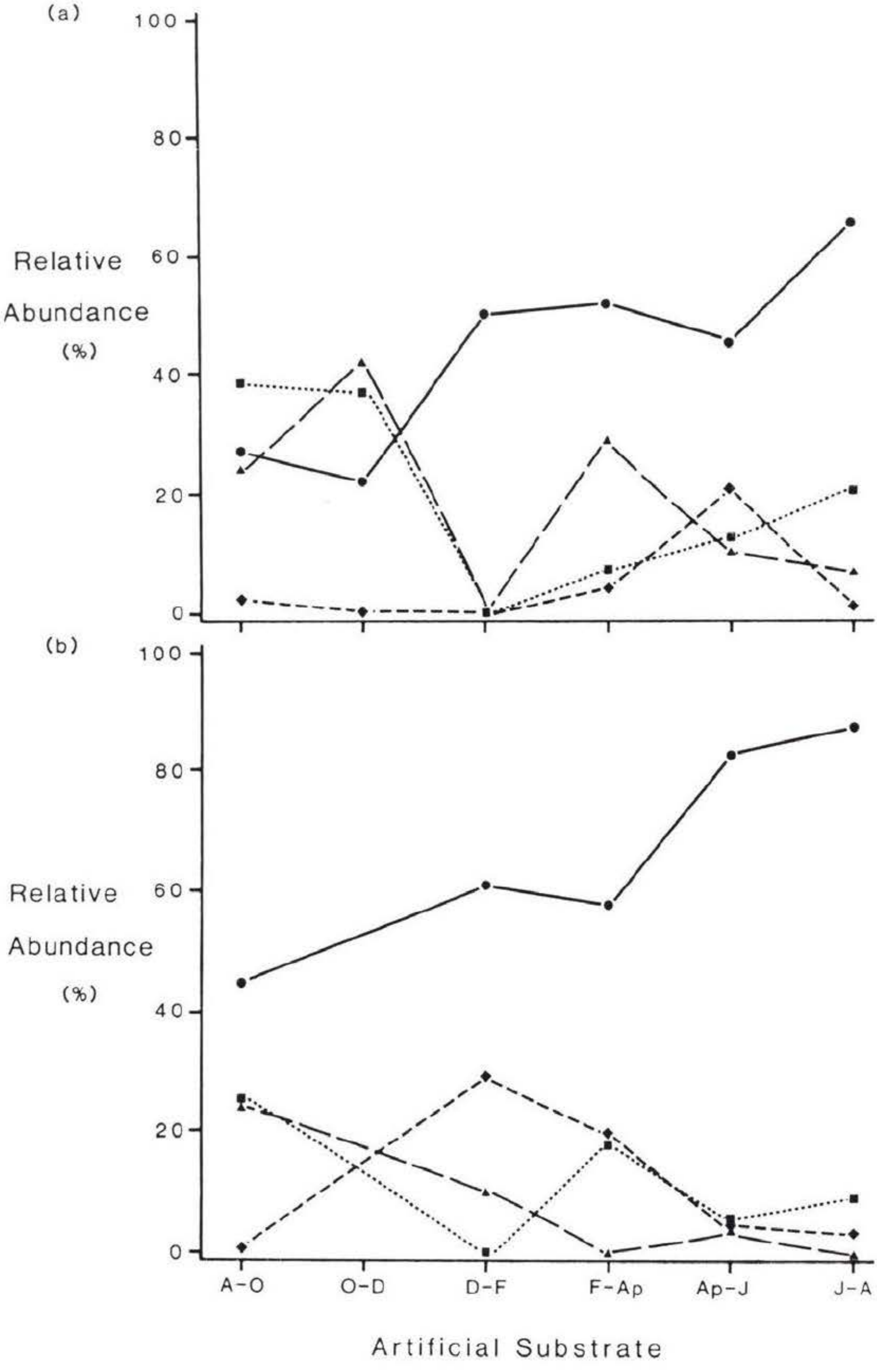
III. Faunal Description

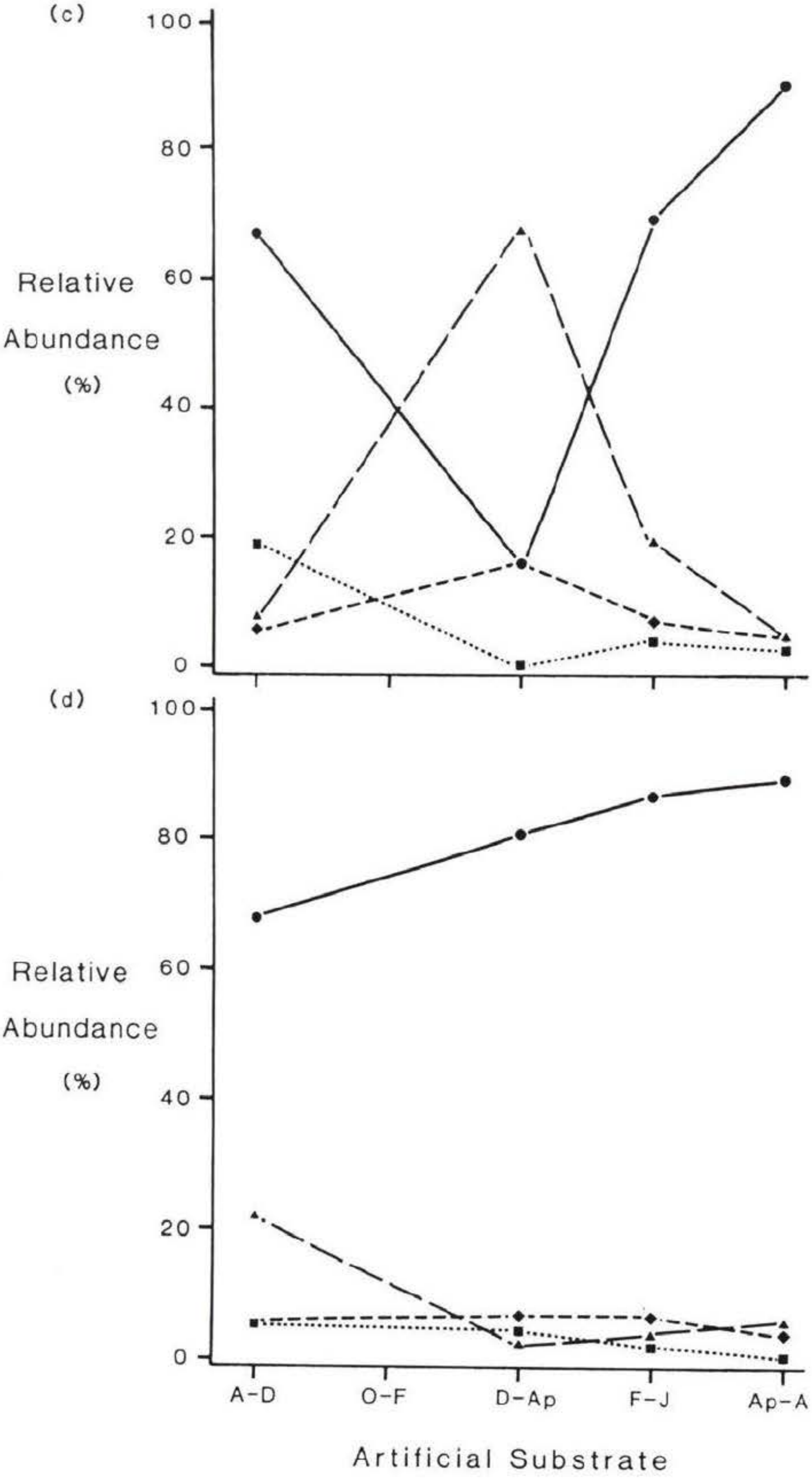
A. General

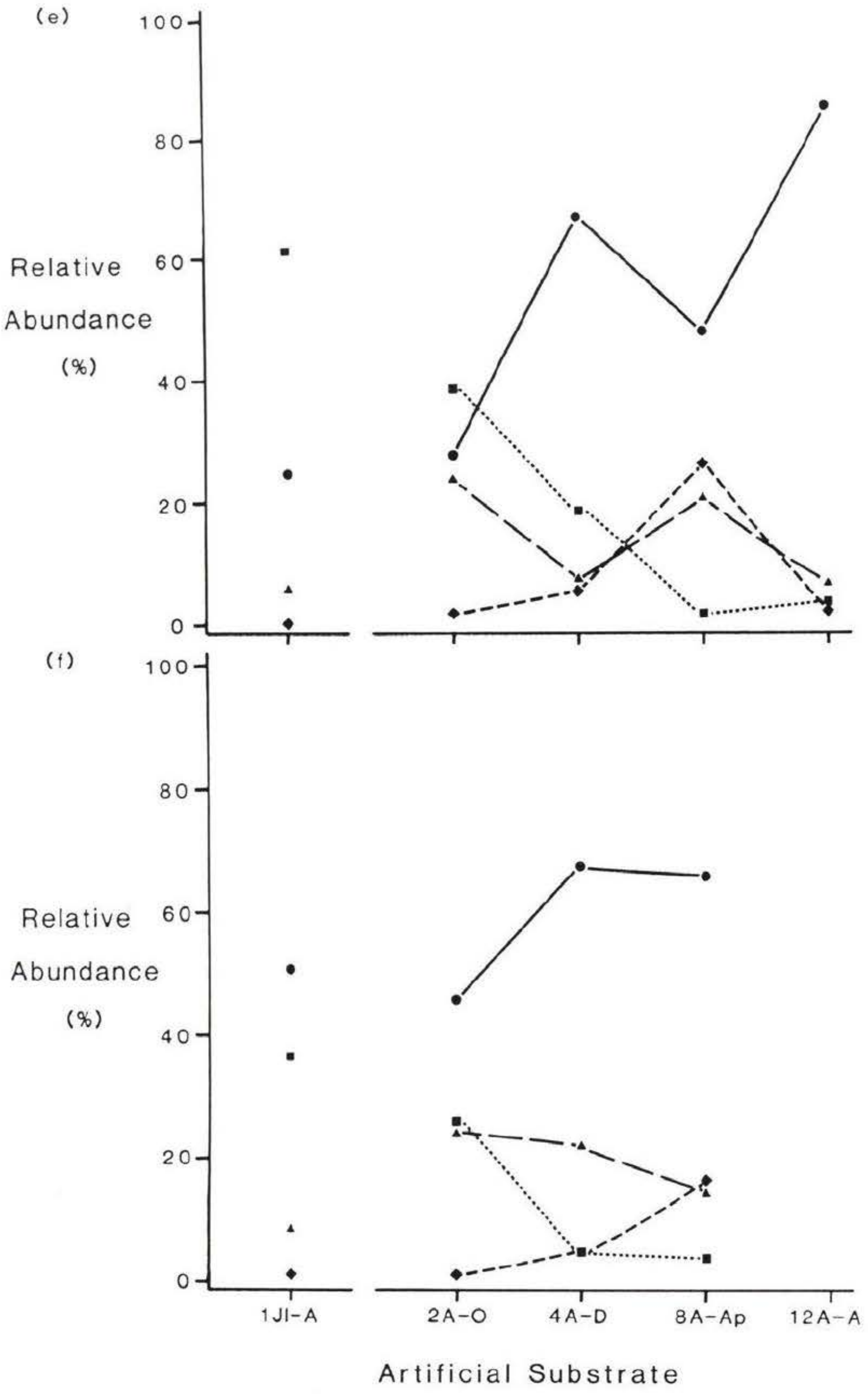
A total of 80 taxa were collected from artificial substrate experiments. Appendix 6 lists taxa and abundances for each container. Prior to data analysis some of the 80 taxa were pooled (see Materials and Methods). This reduced the total number of taxa to 55. Seventy-one percent of the taxa were common to control and tailing boxes, 22% occurred only in controls, and 7% were found exclusively in tailing substrates. Taxa unique to a substrate type all showed low total abundances; i.e. fewer than 7 individuals of each taxa were found throughout the sampling period (Appendix 7).

The major taxonomic groups comprising the fauna were polychaetes, amphipods, gastropods, and pelecypods. All other taxa comprised 0 to 10% of artificial substrate populations. In general, polychaetes dominated the fauna and increased in relative abundance during spring and summer (Figs. 4a-d). The four experimental units initiated in August 1982 (2A-0, 4A-D, 8A-Ap, 12A-A) also demonstrated polychaete dominance and generally showed increases in relative abundance with community age (Figs. 4e,f).
Polychaetes were the only group that was always found in higher numbers in control substrates than in tailings.

Late summer and fall 1 and 2 month tailing containers supported high amphipod populations. Amphipods were the most numerous group in T1J-A and T2A-0,


(a)
100
80
60
40
20
0
Relative
Abundance
(%)
(b)
100
80
60
40
20
0
Relative
Abundance
(%)
A-O
O-D
D-F
F-Ap
Ap-J
J-A
Artificial Substrate


(c)
100
80
60
40
20
0
Relative
Abundance
(%)
(d)
100
80
60
40
20
0
Relative
Abundance
(%)
A-D
O-F
D-Ap
F-J
Ap-A
Artificial Substrate


(e)
100
80
60
40
20
0
Relative Abundance (%)
(f)
100
80
60
40
20
0
Relative Abundance (%)
1JI-A
2A-O
4A-D
8A-Ap
12A-A
Artificial Substrate

and were second in relative abundance after gastropods in T20-D (Figs. 4a,e,f). Corresponding 1 and 2 month control boxes also showed high numbers of amphipods; however this group never attained dominance in controls (Fig. 4b). Counts of amphipods in 1 and 2 month late summer and fall substrates were similar for tailings and controls (Appendix 8). In contrast, the number of polychaetes in controls was at least twice those in tailings. This reduced the relative abundance of amphipods in control populations. Throughout the remainder of the year amphipod relative abundances varied in 2 month containers but never rose above 22%. The amphipod component of 4 month populations was small (Figs. 4c,d) and decreased with length of community development (Figs. 4e,f).

Relative importance of gastropods fluctuated seasonally in 2 and 4 month tailing substrates (Figs. 4a-d). Gastropods dominated the fauna in T20-D and T4A-D. Control containers showed low and variable gastropod relative abundances throughout the year. Seasonal patterns of gastropods in control and tailing substrates did not correspond; thus no overall seasonal trend was evident. Trends in gastropod relative abundance with community age were also not discernable (Figs. 4e,f). Pelecypods also demonstrated erratic relative abundance fluctuations in 2 and 4 month boxes; however, they never dominated the fauna, and generally showed low relative abundances (Figs. 4a-d). Figure 4e,f shows an increase in pelecypod relative abundance with community age until 8 months. Values then dropped sharply in the one 12 month substrate collected.

B. Abundant Taxa

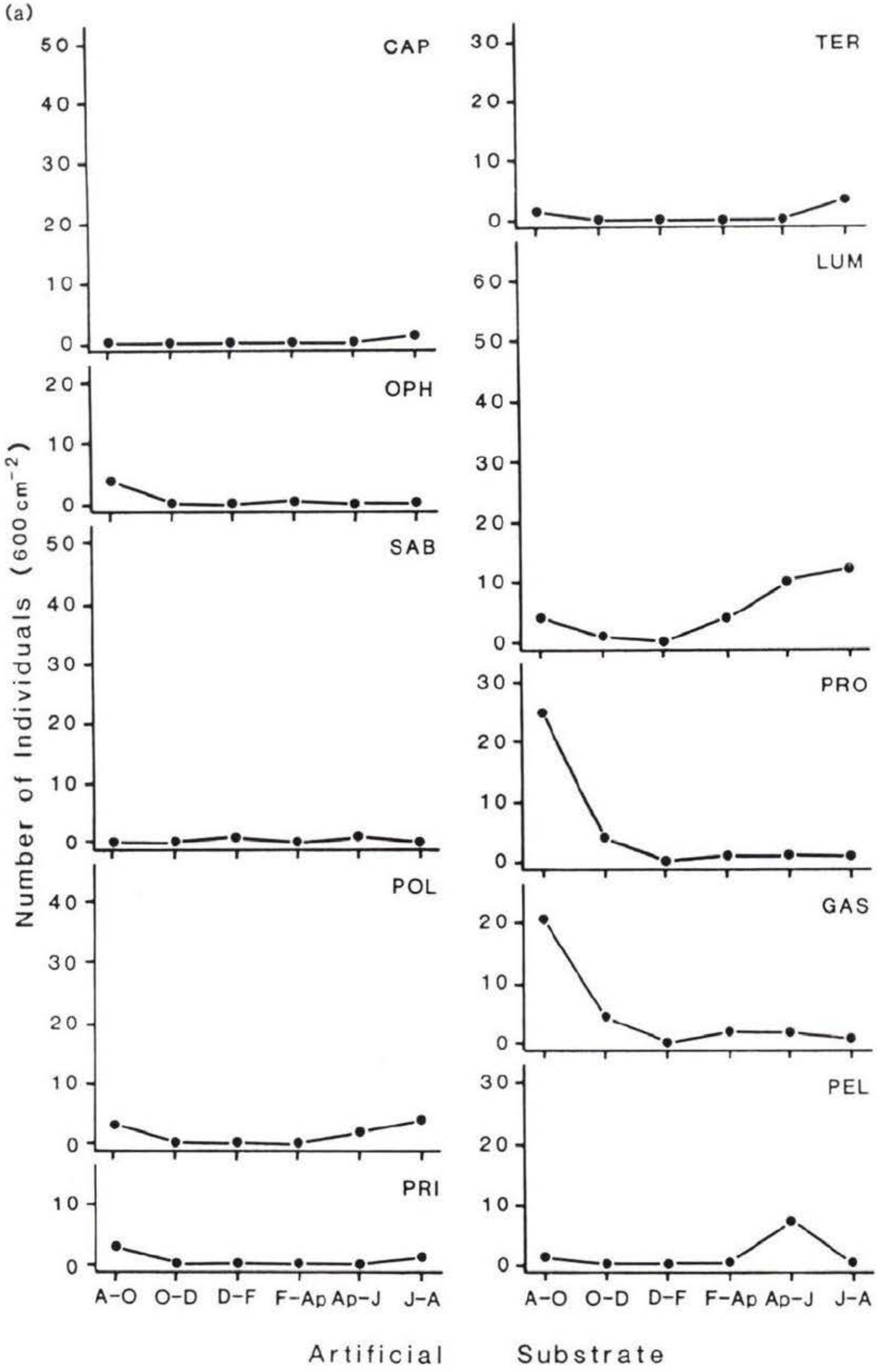
Total abundances of individual taxa were calculated by summing abundances for each taxon from all artificial substrates. Taxa with total abundances greater than 100 were individually examined for seasonal and temporal abundance patterns. Ten taxa met this criterion: Capitellidae, Opheliidae, Sabellidae, *Polydora* sp., *Prionospio* sp., Terebellidae, *Lumbrineris* sp. *Protomedia articulata* Barnard, Gastropoda, and Pelecypoda. The first two axes of a non-centred principal components analysis (PCA) of taxa, also separated these ten most abundant taxa from the remaining organisms. Of these ten, nine were among the ten most abundant taxa in both control and tailing artificial substrates. *Lumbrineris* sp. was the most abundant taxon in both substrates.

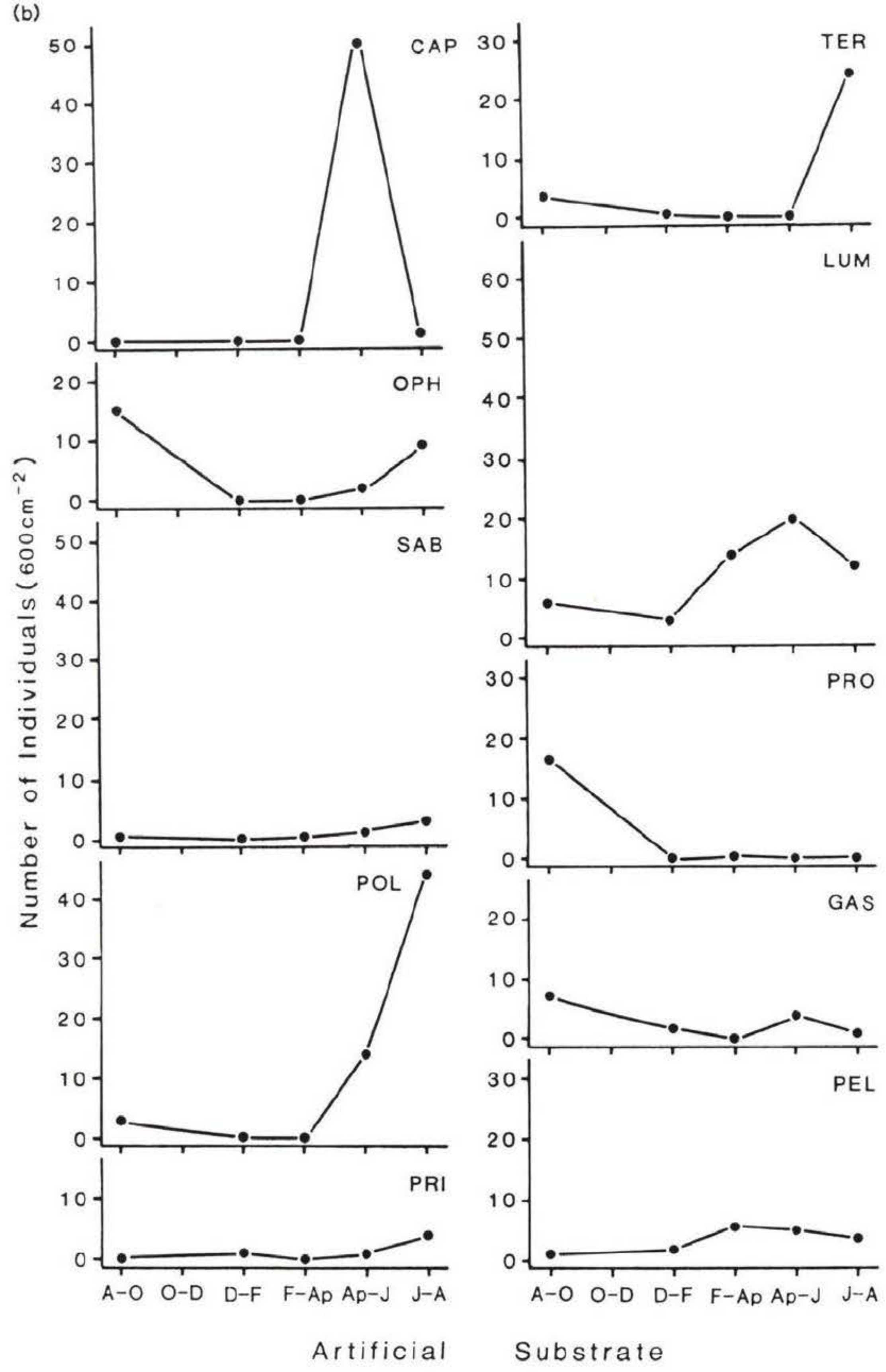
Figure 5a-b displays seasonal abundance fluctuations in 2 month containers for each of the ten taxa. Generally, numbers of all organisms were low over the winter. Patterns of abundance in spring, summer, and fall differed between taxa; however most increased in abundance from winter levels. Polychaete taxa in 2 month tailing substrates showed only slight elevations in numbers during the spring to fall period. In contrast, abundance of the amphipod *Protomedia articulata* rose sharply in the fall. During this season *P. articulata* comprised 90 to 100% of the amphipod population and therefore was the species responsible for the amphipod dominance of fall 2 month tailing containers. Gastropod numbers were also high in fall tailing boxes; however, their dominance of the T20-D community was not a result of high gastropod abundances, but instead reflected a decline in abundances of other taxa.

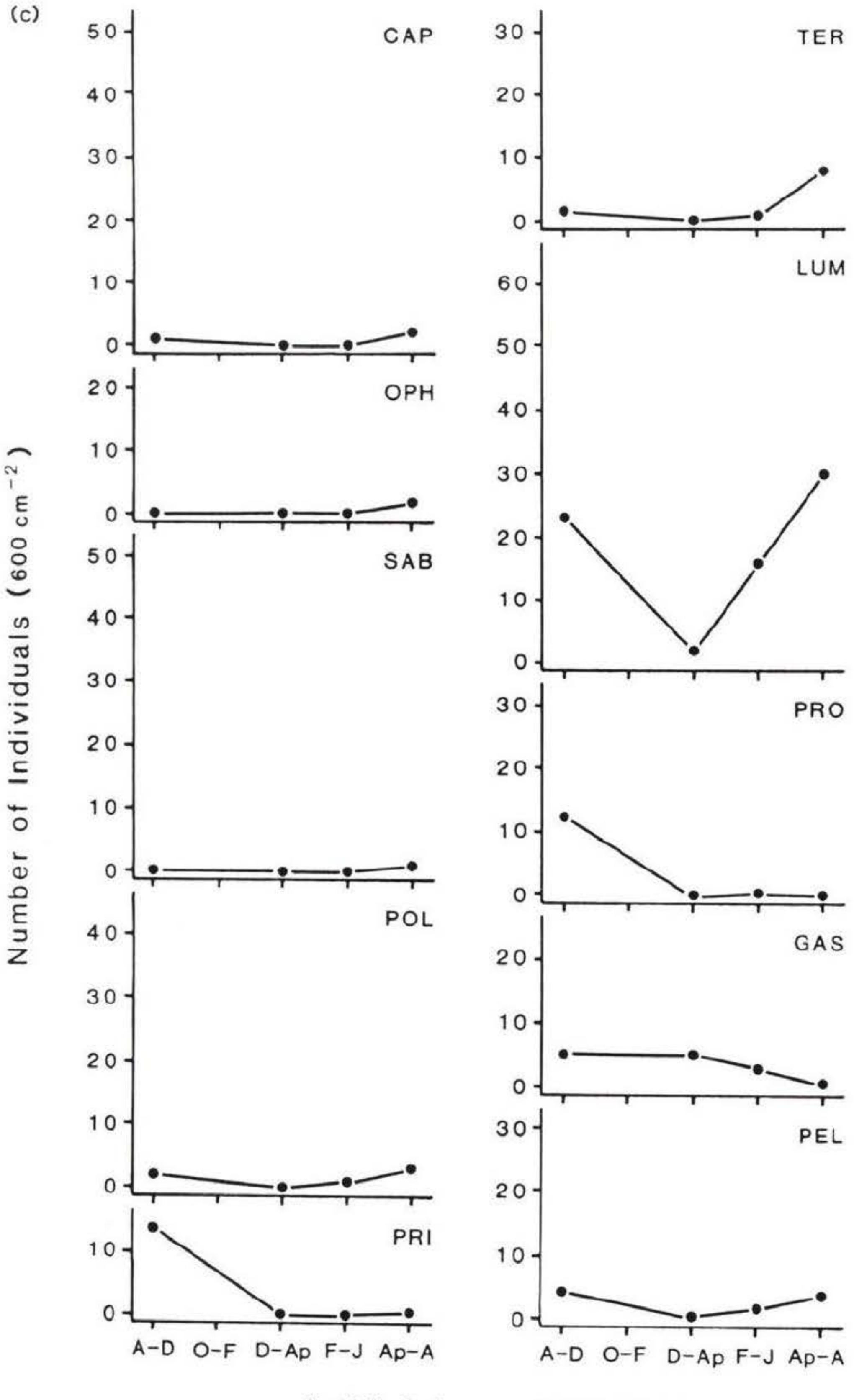
Figure 5: Abundances of the 10 abundant taxa found in artificial substrates.

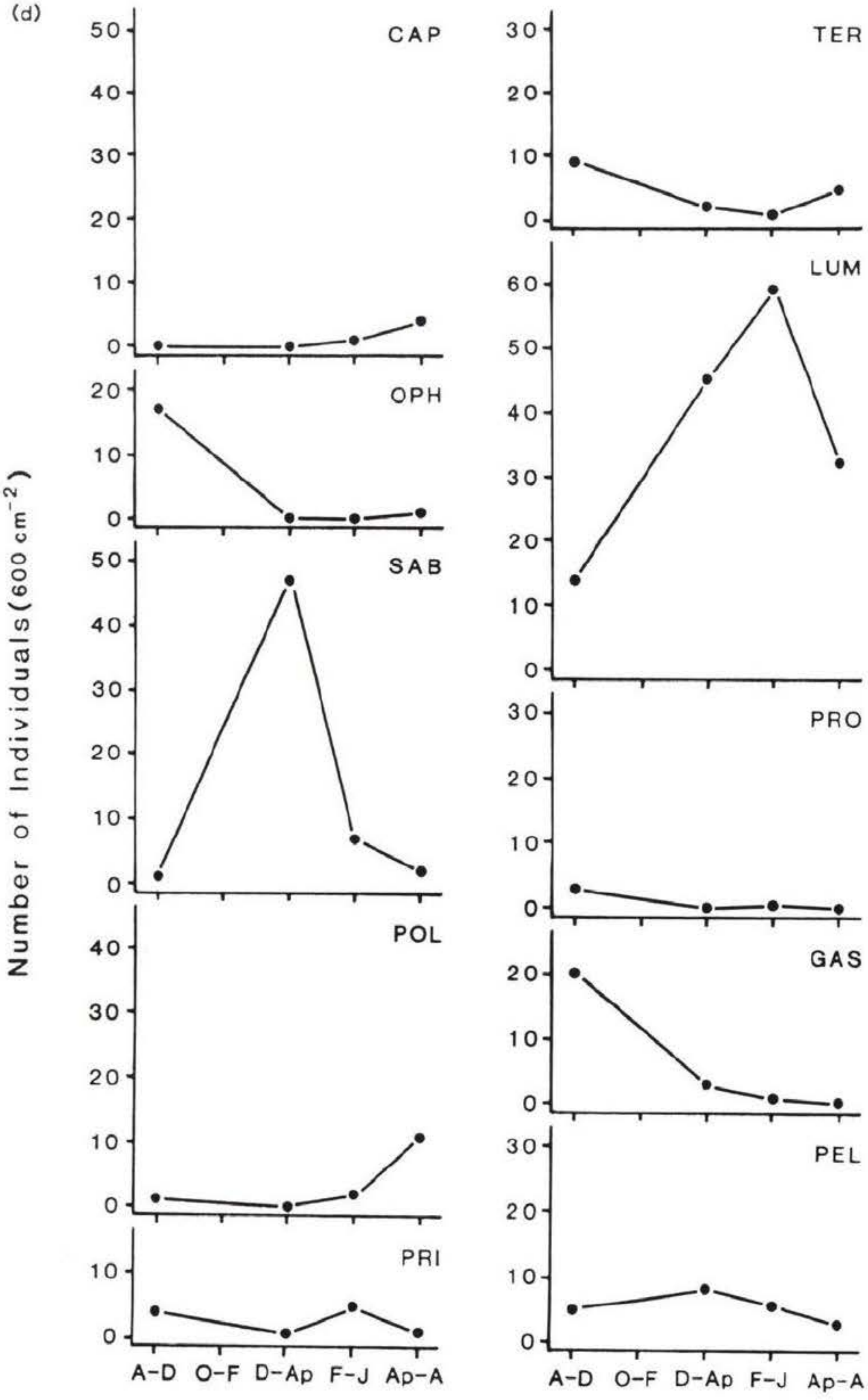
Capitellidae-CAP, Opheliidae-OPH, Sabellidae-SAB, *Polydora* sp.-POL, *Prionospio* sp.-PRI, Terebellidae-TER, *Lumbrineris* sp.-LUM, *Protomedia articulata* -PRO, Gastropoda-GAS, Pelecypoda-PEL. Points are means of two replicate artificial substrates, except where a replicate was lost (Table 1) then n=1. See table 1 for artificial substrate codes.

(a) Tailing 2 month artificial substrates.
(b) Control 2 month artificial substrates.
(c) Tailing 4 month artificial substrates.
(d) Control 4 month artificial substrates.
(e) Tailing artificial substrates initiated in August 1982.
(f) Control artificial substrates initiated in August 1982.


(a)
CAP
OPH
SAB
POL
PRI
TER
LUM
PRO
GAS
PEL
Number of Individuals (600 cm^{-2})
0
10
20
30
40
50
60
A-O
O-D
D-F
F-Ap
Ap-J
J-A
Artificial Substrate

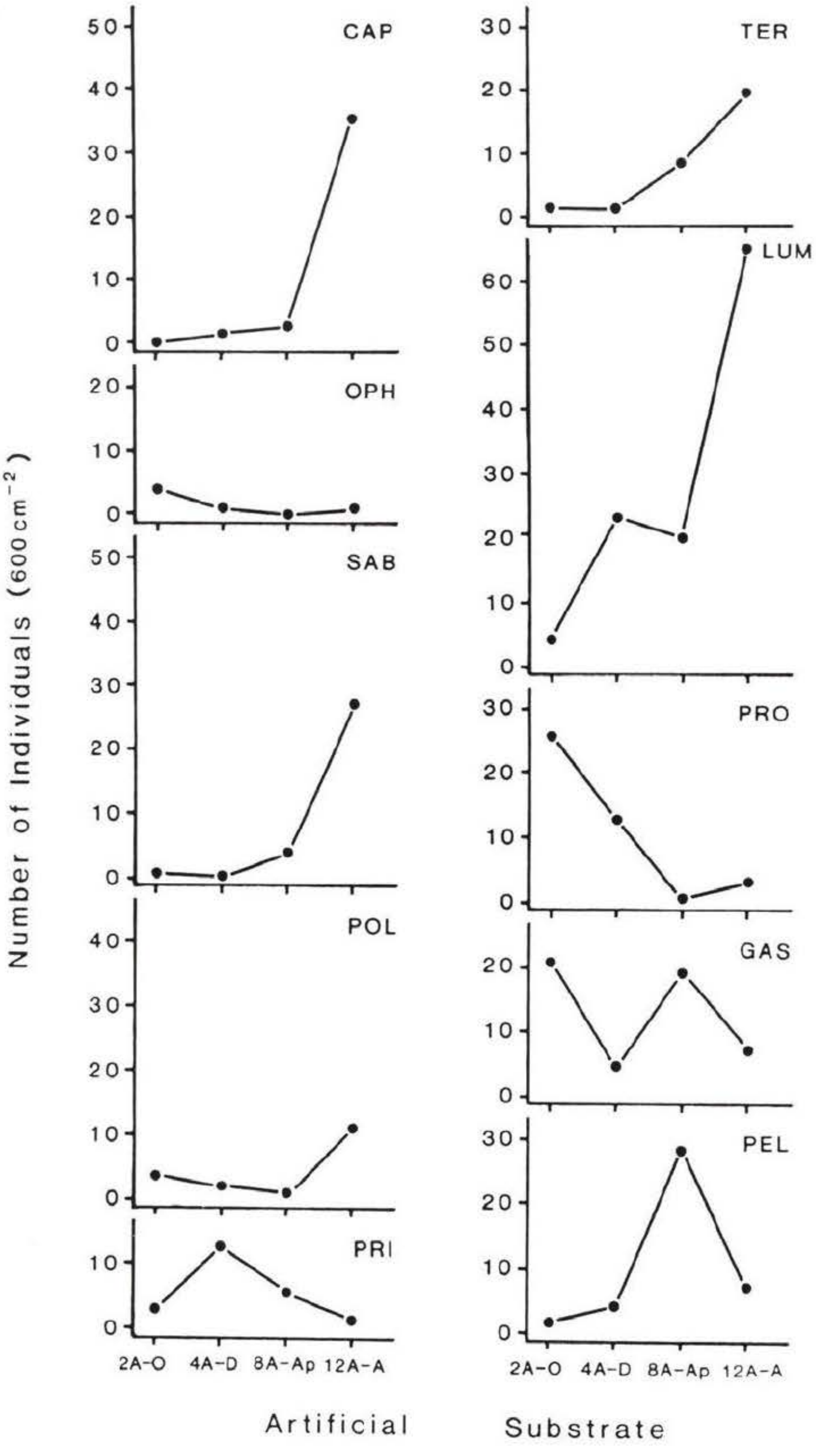

(b)
Number of Individuals (600cm⁻²)
CAP
50
40
30
20
10
0
OPH
20
10
0
SAB
50
40
30
20
10
0
POL
40
30
20
10
0
PRI
10
0
A-O O-D D-F F-Ap Ap-J J-A
TER
30
20
10
0
LUM
60
50
40
30
20
10
0
PRO
30
20
10
0
GAS
20
10
0
PEL
30
20
10
0
A-O O-D D-F F-Ap Ap-J J-A
Artificial Substrate


(c)
CAP
OPH
SAB
POL
PRI
TER
LUM
PRO
GAS
PEL
0
10
20
30
40
50
60
A-D
O-F
D-Ap
F-J
Ap-A
Number of Individuals (600 cm^{-2})
Artificial Substrate

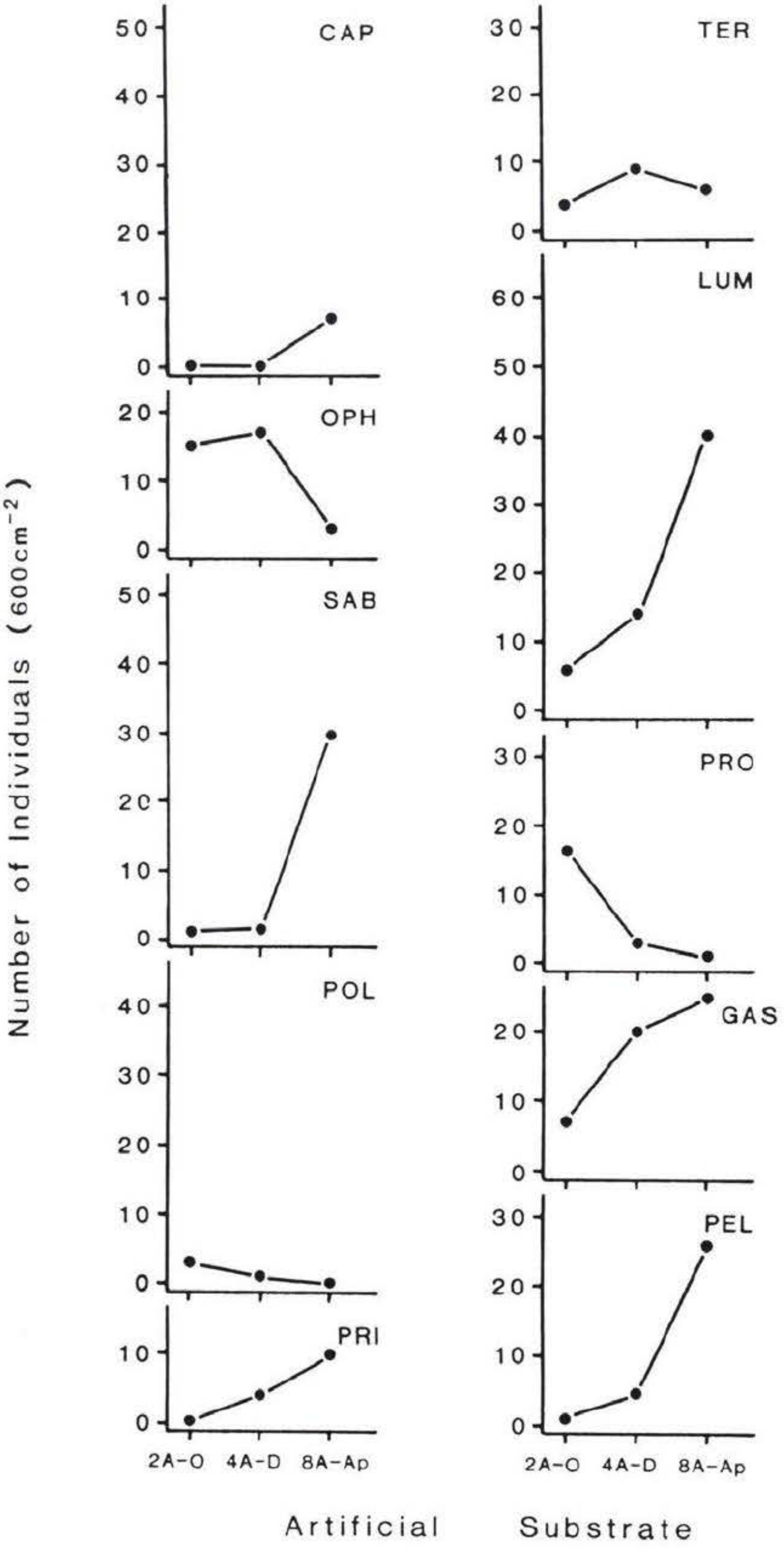


Artificial Substrate

(e)


Number of Individuals (600 cm^{-2})
CAP
OPH
SAB
POL
PRI
TER
LUM
PRO
GAS
PEL
0
10
20
30
40
50
60
2A-O
4A-D
8A-Ap
12A-A
Artificial Substrate

(f)


Number of Individuals (600cm^{-2})
CAP
0
10
20
30
40
50
OPH
0
10
20
SAB
0
10
20
30
40
50
POL
0
10
20
30
40
PRI
0
10
2A-O
4A-D
8A-Ap
TER
0
10
20
30
LUM
0
10
20
30
40
50
60
PRO
0
10
20
30
GAS
0
10
20
PEL
0
10
20
30
2A-O
4A-D
8A-Ap
Artificial Substrate

The majority of polychaete taxa in 2 month control substrates demonstrated higher spring to fall maximum abundances than did their tailing counterparts (Figs. 5a,b). In addition, seasonal patterns in abundance of individual taxa often differ markedly between control and tailing 2 month containers. Within controls, taxa demonstrated wide variability in their seasonal abundance patterns.

Control 2 month boxes experienced a fall increase in *P. articulata* (Fig. 5b) similar to that observed in tailings. However, amphipods did not dominate fall controls as they had tailings, because populations of other organisms were higher in fall controls than in corresponding tailings (Appendix 8).

Four month artificial substrates displayed different patterns in seasonal abundance of individual taxa, both within and between tailing and control containers (Figs. 5c,d). Tailing substrates demonstrated low numbers of most taxa in the early spring (T4-Ap). *Protomedia articulata* abundances peaked in fall 4 month tailing containers. This corresponded with the peak in 2 month boxes.

Select taxa in 4 month control substrates did reach early spring minima; however, numbers of sabellids and *Lumbrineris* sp. rose sharply over this period where as pelecypods showed no drop in numbers (Figs. 5c,d). A large increase in *P. articulata* numbers was absent from 4 month controls.

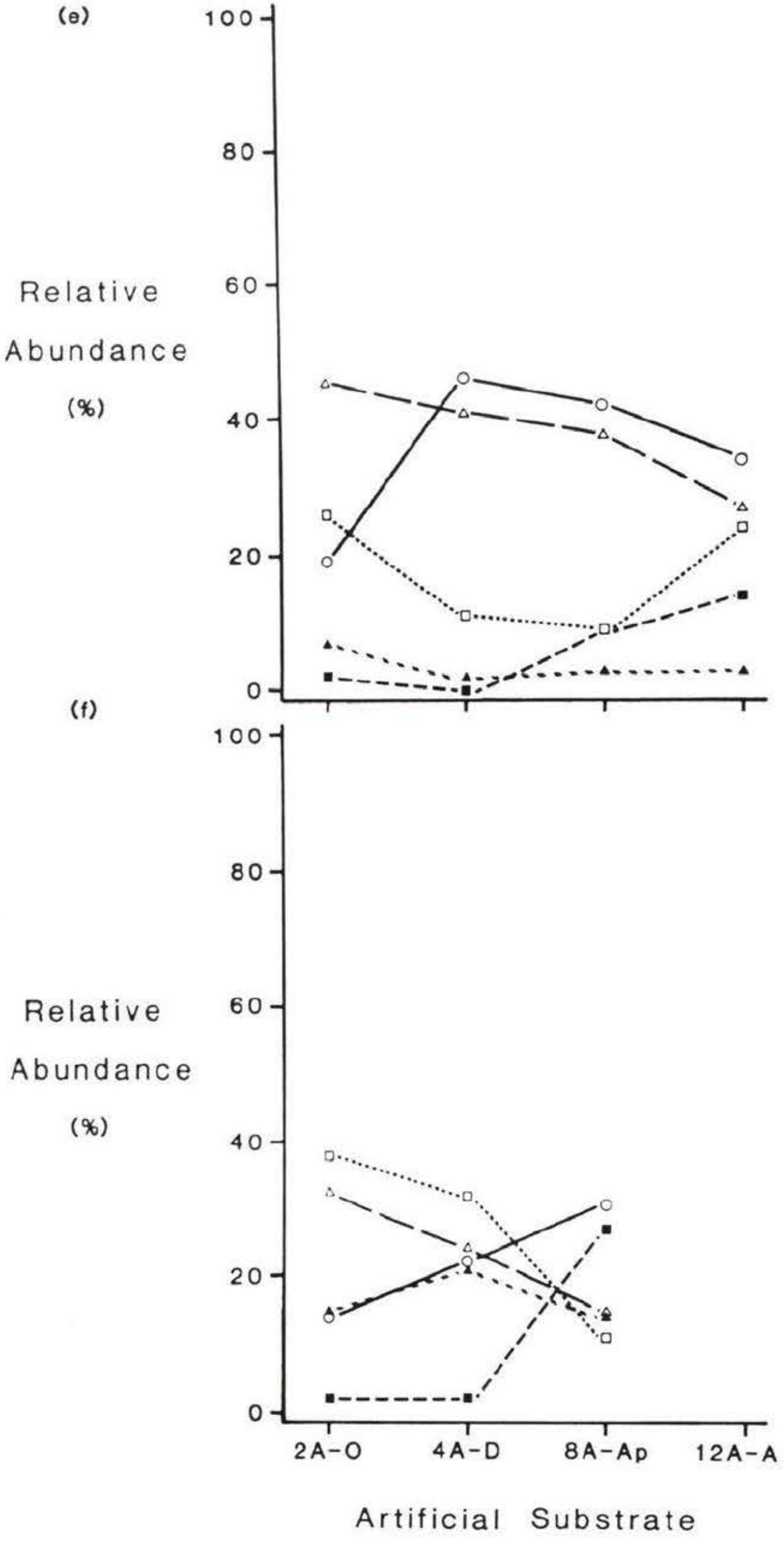
Examination of abundances of individual taxa as the community ages yields a wide variety of responses (Figs. 5e,f). Capitellids, sabellids and *Lumbrineris* sp. increased with time in control and tailing substrates. *Protomedia articulata* abundances decreased. Pelecypod numbers rose from 2 to 8 months, but showed a sharp decline in T12A-A. Apart from these general trends, individual taxa demonstrated different abundance patterns in control and tailing substrates with time, and few trends are evident within a treatment.

C. Polychaete Feeding Modes

Polychaetes were divided into feeding modes following Fauchald and Jumars' (1979) classification system. Members of the genus *Lumbrineris* could not be placed in an established feeding mode, as they have been variously described as herbivores, deposit feeders, and carnivores (Fauchald and Jumars, 1979). Therefore, an undefined mode was established to contain the *Lumbrineris* species. Five major modes of nutrition are recognized by Fauchald and Jumars: herbivores, surface deposit feeders, subsurface deposit feeders, filter feeders, and carnivores. Of these, herbivores were the only group not found inhabiting artificial substrates.

In 2 month containers the relative abundance, and position of each of the feeding modes in the population changed constantly through the year (Figs. 6a,b). The identity of the numerically dominant group also changed over the sampling period. Dominance shifted between *Lumbrineris* , surface deposit feeders and subsurface deposit feeders. Relative abundances of feeding modes in 2 month tailing and control substrates showed few similarities; however *Lumbrineris* dominated both 2F-Ap populations.

Four month containers also showed fluctuations in relative importance and numerical abundance of feeding modes (Figs. 5c,d). *Lumbrineris* tended to dominate the 4 month populations, although filter feeders and surfaced deposit feeders


(e)
(f)
Relative Abundance (%)
0
20
40
60
80
100
2A-O
4A-D
8A-Ap
12A-A
Artificial Substrate

replaced them in C4D-Ap and C4A-D, respectively. No corresponding peak in filter feeders was evident in either 2 or 4 month tailing boxes or in 2 month controls (Figs. 6a,b,c). Tailing and control 4 month substrates both showed a decrease in relative abundance of surface and subsurface deposit feeders in the early spring. This was matched by an increase in *Lumbrineris* (Figs. 6c,d).

Polychaete trophic diversity did not appear to increase with community age (Figs. 6e,f). The five feeding modes were present in all but one of the 2, 4, 8, and 12 month containers started in August, 1982. Feeding modes did not show any clear successional patterns over the August time series. Control and tailing substrates started in August demonstrated little similarity in relative abundances of feeding modes.

IV. Replication for Statistical Analysis

Artificial substrate experiments were replicated; however some replicates were lost (Table 1). Similarity of replicate containers was tested by running Students T or Mann-Whitney U tests on each replicate pair. T-tests were used when variances were homogeneous, and Mann-Whitney U tests employed when this condition was not met. Two sets of tests were done, one on the number of individuals, the other on the number of taxa. Control pairs showed no significant differences for the two parameters tested, while only two of the thirteen tailing pairs were significantly different in both number of individuals and taxa (Table 4). On the basis of these results replicates were pooled for all further statistical analyses.

Table 4: The significance of students T-Tests (T) and Mann-Whitney U Tests (U) comparing replicate artificial substrates on the basis of: (1) the number of individuals, and (2) the number of taxa.

(*): significant difference (p = 0.05). (-): no significant difference. n = 6 for each replicate. See table 1 for artificial substrate codes.

Replicate Pair of Artificial Substrates	Number of Individuals		Number of Taxa	
	Test Used	Significant Difference	Test Used	Significant Difference
T1J1-A	T	-	T	-
T2A-O	T	-	T	-
T2O-D	T	-	T	-
T2D-F	T	-	T	-
T2F-Ap	T	-	T	-
T2Ap-J	T	-	T	-
T2J-A	T	-	T	-
T4A-D	T	-	T	*
T4D-Ap	T	*	T	*
T4F-J	T	-	T	-
T4Ap-A	T	*	T	*
T8A-Ap	T	-	T	-
C1J1-A	T	-	T	-
C2A-O	T	-	T	-
C2D-F	T	-	T	-
C2F-Ap	U	-	U	-
C2Ap-J	T	-	T	-
C2J-A	T	-	T	-
C4D-Ap	T	-	T	-
C4F-J	T	-	T	-
C4Ap-A	T	-	T	-

The percent of taxa common to both replicates was calculated as a percent of the sum of the total taxa in each replicate. For example if replicate a and b contained 4 and 5 taxa respectively, the total number of taxa is 9. If two taxa were common to both replicates, then 4 of the nine are common taxa, thus the percent of taxa in common is 44%. On average 56% ±11.91 (SD) (n=20) of the taxa in artificial substrates were common to both replicates.

V. The Effect of Exposure Length, Substrate Type, and Season on the Number of Individuals and Taxa, and Diversity

Figures 7 and 8 display seasonal fluctuations in the number of individuals and taxa in 2 and 4 month tailing and control artificial substrates. These abundance and richness data were analysed using three-way analyses of variance. Factors in the ANOVAs were: (1) exposure length, levels = 2 and 4 months; (2) substrate type, levels = tailing and control; and (3) season, levels = experiment starting date - August, December, February, and April. Data from October and June were incomplete, and therefore were not included in the ANOVAs. October and June data points fit into the trends described by the analysed data (Figs. 7,8). The log (x + 1) transformation was applied to the data to achieve the variance homogeneity required for analysis of variance. For comparative purposes ANOVA results from the untransformed data are also reported.

Three-way ANOVAs on log-transformed and untransformed data found significant exposure length, substrate, and seasonal effects, for both abundance and richness (Table 5). The majority of two-way and the three-way interactions were

Figure 7: The number of individuals and taxa found in experimental and control artificial substrates.

2 month substrates-circles, 4 month substrates-triangles. Points are means of 12 samples, except where a replicate was lost (Table 1) then n=6. Bars represent 95% confidence intervals. See table 1 for artificial substrate codes.

(a) The number of individuals in tailing artificial substrates.
(b) The number of individuals in control artificial substrates.
(c) The number of taxa in tailing artificial substrates.
(d) The number of taxa in control artificial substrates.

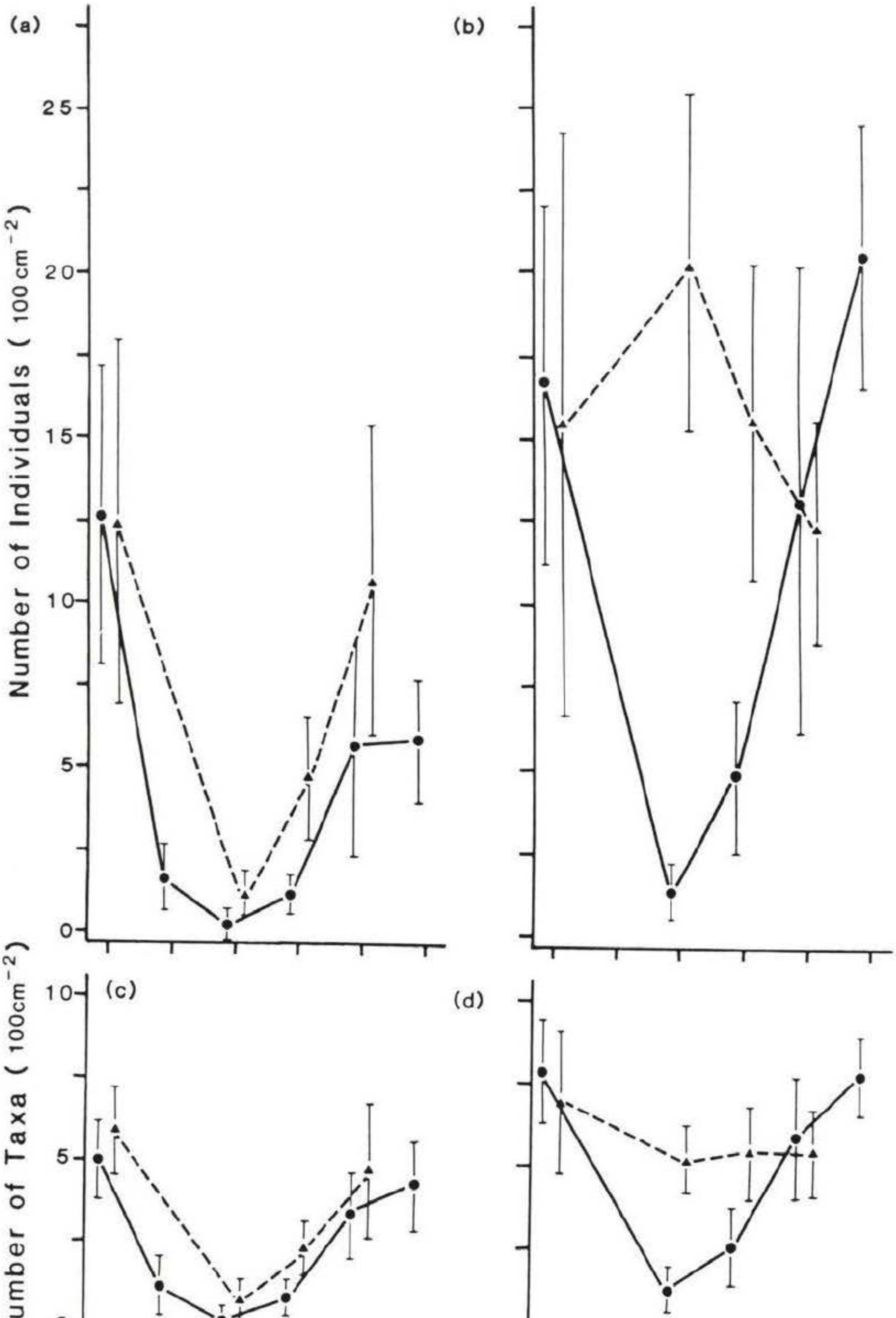

(a)
(b)
(c)
(d)
Number of Individuals (100 cm^{-2})
Number of Taxa (100cm^{-2})
0
5
10
15
20
25
0
5
10
A
O
D
F
Ap
J
Month of Artificial Substrate Initiation

Figure 8: The number of individuals and taxa found in 2 and 4 month artificial substrates.

Tailing substrates-circles, control substrates-triangles. Points are means of 12 samples, except where a replicate was lost (Table 1) then n=6. Bars represent 95% confidence intervals. See table 1 for artificial substrate codes.

(a) The number of individuals in 2 month artificial substrates.
(b) The number on individuals in 4 month artificial substrates.
(c) The number of taxa in 2 month artificial substrates.
(d) The number of taxa in 4 month artificial substrates.

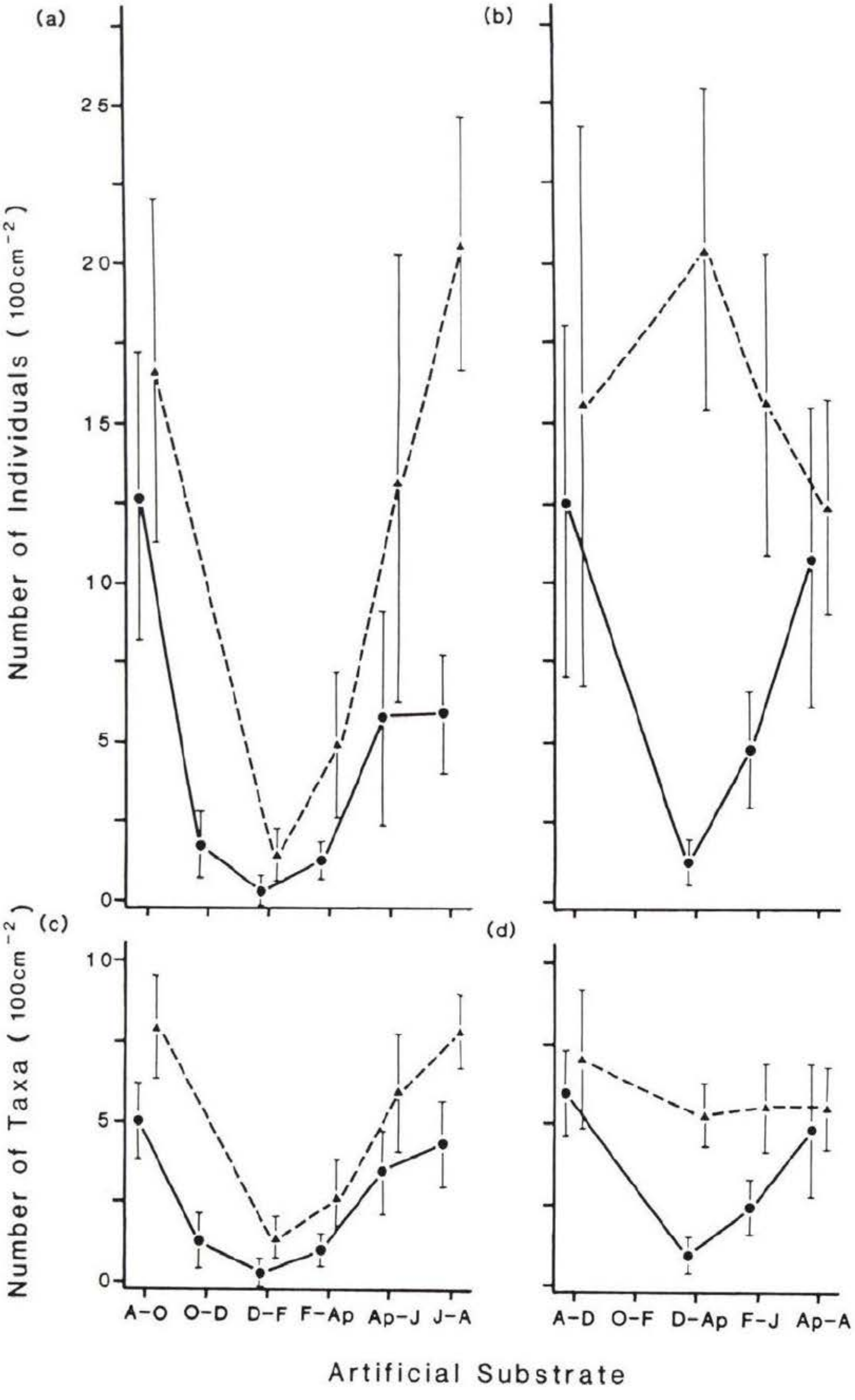

(a)
(b)
(c)
(d)
25
20
15
10
5
0
Number of Individuals (100cm^{-2})
Number of Taxa (100cm^{-2})
10
5
0
A-O
O-D
D-F
F-Ap
Ap-J
J-A
A-D
O-F
D-Ap
F-J
Ap-A
Artificial Substrate

Table 5: **Probability values from three-way ANOVAs on the effects of exposure length, substrate type, and season on the number of individuals and taxa in 2 and 4 month artificial substrates.**

Substrates initiated in October and June were not included in the analysis. Probability values are from; (A) transformed (log[x+1]) data, and (B) untransformed data. Total degrees of freedom = 185.

Effect	df	Number of Individuals		Number of Taxa	
		A	B	A	B
Exposure length	1	<0.01	<0.01	<0.01	<0.01
Substrate	1	<0.01	<0.01	<0.01	<0.01
Season	3	<0.01	<0.01	<0.01	<0.01
Exposure length x substrate	1	<0.01	<0.01	0.39	0.48
Exposure length x season	3	<0.01	<0.01	<0.01	0.02
Substrate x season	3	<0.01	0.12	<0.01	0.57
Exposure length x substrate x season	3	<0.01	<0.01	0.03	<0.01

also significant (Table 5). A significant three-way interaction indicates that simple interaction effects of two variables are not the same at different levels of the third variable (Kepple, 1973); thus main effects may be compounded. Figures 7 and 8 also illustrate the presence of several distinct interactions within the data. The substrate effect is not overly affected by interactions. In all cases, control containers supported a higher number of individuals and taxa than did the tailing substrates exposed for the same period (Fig. 8). Interactions do confuse the effect of exposure length and season. Generally, tailing 4 month substrates had higher abundances and richness than their 2 month counterparts (Fig. 7). Control containers show no clear effect of exposure length, as neither 2 or 4 month boxes had the highest number of individuals or taxa for all sampling dates (Fig. 7). There is an obvious seasonal trend in 2 month substrates, while 4 month control and tailing substrates describe two separate and distinct seasonal trends (Figs. 8). To adequately elucidate these complex responses within factor levels, it was necessary to examine simple effects within the three-way ANOVA design. Exact probability levels reported for simple effects must be interpreted with caution, as simple effects tested were not orthogonal.

A. Exposure Length Effect

The effects of exposure length on abundance and richness in artificial substrates were tested within control and tailing substrates. In tailing containers, the significance of an exposure effect on abundance is ambiguous, as tests using log transformed data found significance, while those using untransformed data did not (Table 6). Examination of figure 7a demonstrate that 95% confidence intervals for containers started in August overlap substantially, as do those for boxes initiated in April. Confidence intervals for December and February show little crossing. This suggests that abundance differences between 2 and 4 month tailing substrates only existed for part of the sampling period. Further evidence of this is the presence of a significant exposure length x season interaction in the logged data (Table 6), which reflects changes in the magnitude of differences between 2 and 4 month containers, over the sampling time.

Differences between the number of taxa in 2 and 4 month tailing substrates describe a much clearer pattern. Tests on logged and untransformed data found that 4 month containers had significantly more taxa than 2 month containers, and that no significant exposure length x season interaction was present (Table 6). Ninety-five percent confidence intervals for richness overlap for the same containers that showed overlap for abundance (Figs. 7a,c).

Examination of the effect of exposure length on abundance and richness within control substrates yields a complex picture. Analysis of simple effects detects a significant difference between 2 and 4 month containers, in both numbers of individuals and taxa (Table 6). However, the two exposure length x season interactions are also highly significant, indicating that 2 and 4 month substrates displayed very different seasonal patterns (Figs. 7b,d). Four month substrates initiated in August and April had lower numbers of individuals and taxa than 2 month substrates started in these months. Ninety-five percent confidence intervals in August and April show almost complete overlap. In contrast, 4 month containers exposed in December and February supported much higher numbers of individuals

Table 6: Probability values from tests of simple effects, within a three-way ANOVA design, of exposure length, substrate type, and season on the number of individuals and taxa in 2 and 4 month artificial substrates (AS).

Substrates initiated in October and June were not included in the analysis. Probability values are from; (A) transformed (log[x+1]) data, and (B) untransformed data. Total degrees of freedom = 185. AS: artificial substrates.

Simple Effect	df	Number of Individuals		Number of Taxa	
		A	B	A	B
Exposure length within tailing AS	1	<0.01	0.07	<0.01	<0.01
Exposure length x season within tailing AS	3	0.05	0.48	0.36	0.89
Exposure length within control AS	1	<0.01	<0.01	<0.01	<0.01
Exposure length x season within control AS	3	<0.01	<0.01	<0.01	<0.01
Substrate within 2 month AS	1	<0.01	<0.01	<0.01	<0.01
Season within 2 month AS	3	<0.01	<0.01	<0.01	<0.01
Substrate x season within 2 month AS	3	0.30	0.42	0.86	0.32
Substrate within 4 month AS	1	<0.01	<0.01	<0.01	<0.01
Season within 4 month AS	3	<0.01	0.28	<0.01	<0.01
Substrate x season within 4 month AS	3	<0.01	<0.01	<0.01	<0.01

and taxa than the corresponding 2 month boxes. Confidence intervals for these pairs do not overlap. Due to the presence of this type of interactive effect in controls, significance of an exposure effect has little meaning. Instead, it appears that differences between 2 and 4 month containers only existed during the winter and early spring.

B. Substrate Effect

Tests of simple effects within 2 and 4 month artificial substrates demonstrated that in both time periods, control containers supported significantly higher numbers of individuals and taxa than tailings (Table 6). Two month control substrates contained an average of 3.4 ±1.8(SD) times the number of individuals and 2.6 ±1.6 (SD) times the number of taxa than did tailings. Substrate x season interactions within 2 month substrates were not significant, as seasonal responses in abundance and richness were similar in control and tailings (Figs. 8a,c). Despite the similarity in seasonal patterns, figure 8 shows differences between substrate types increasing from winter to summer. In contrast the ratios between control and tailing substrates for the number of individuals and taxa reached minima in the fall (1.3 and 1.6 respectively), and maxima in winter (6.0 and 5.3 respectively).

Differences in abundance and richness between paired control and tailing boxes exposed for the same time period, were tested using one-tailed t-tests. The results suggest that controls were significantly higher than tailings in all 2 month pairs, except abundance values for the substrates initiated in August (Table 7). The similarity of the 2 month August containers is further supported by the substantial overlap of their 95% confidence intervals (Fig. 8a).

Table 7: Significance of one-tailed Students' T-tests (T) and Mann-Whitney U tests (U) comparing experimental and control artificial substrates on the basis of: (1) the number of individuals, and (2) the number of taxa.

(*): significant difference (p = 0.05). (-): no significant difference.

Artificial Substrates		n	Number of Individuals		Number of Taxa	
			Test Used	Significant Difference	Test Used	Significant Difference
1A-J	T	12	U	*	U	*
	C	12				
2A-0	T	12	T	-	T	*
	C	12				
2D-F	T	12	T	*	T	*
	C	12				
2F-Ap	T	12	U	*	U	*
	C	12				
2Ap-J	T	12	U	*	T	*
	C	12				
2J-A	T	12	U	*	T	*
	C	12				
4A-D	T	12	T	-	T	-
	C	6				
4D-Ap	T	12	U	*	U	*
	C	12				
4F-J	T	12	U	*	T	*
	C	12				
4Ap-A	T	12	T	-	T	-
	C	12				
8A-Ap	T	12	U	*	T	*
	C	6				
8O-J	T	6	U	*	T	*
	C	6				

Highly significant substrate x season interactions were found within 4 month substrates (Table 6). These resulted because tailing and control substrates described quite different seasonal patterns in both abundance and richness (Figs. 8b,d). The divergent seasonal patterns do not obscure the substrate effect. Control 4 month containers consistently supported higher numbers of individuals and taxa than tailings, and contained an average of 5.6 ±7.2(SD) times the number of individuals and 2.4 ±1.9(SD) times the number of taxa than tailings. However, a seasonal fluctuation in differences between substrate types is evident (Figs. 8b,d). Differences in fall and summer are small, and increase dramatically over the winter and spring. Proportional differences between substrate types also follow this trend. Controls contained 16.3 times the number of individuals and 5.3 times the number of taxa in early spring than did tailings. In the fall, controls contained 1.2 times the number of individuals and 1.2 times the number of taxa than tailings. Ninety-five percent confidence intervals for fall (4A-D) and summer (4Ap-A) substrates overlap considerably (Figs. 8b,d), and one-tailed t-tests on abundance and richness suggest that control and tailings were not significantly different within these pairs (Table 7). Over the winter and spring no part of the 95% confidence intervals coincide (Figs. 8b,d), and one-tailed t-test suggest that substrate types are significantly different (Table 7).

C. Seasonal Effect

A significant seasonal effect in abundance and richness is evident within 2 month artificial substates (Table 6). Control and tailing containers had high fall values, followed by winter declines and subsequent spring to summer increases (Figs. 8a-c). No significant interaction is present (Table 6).

F. Diversity

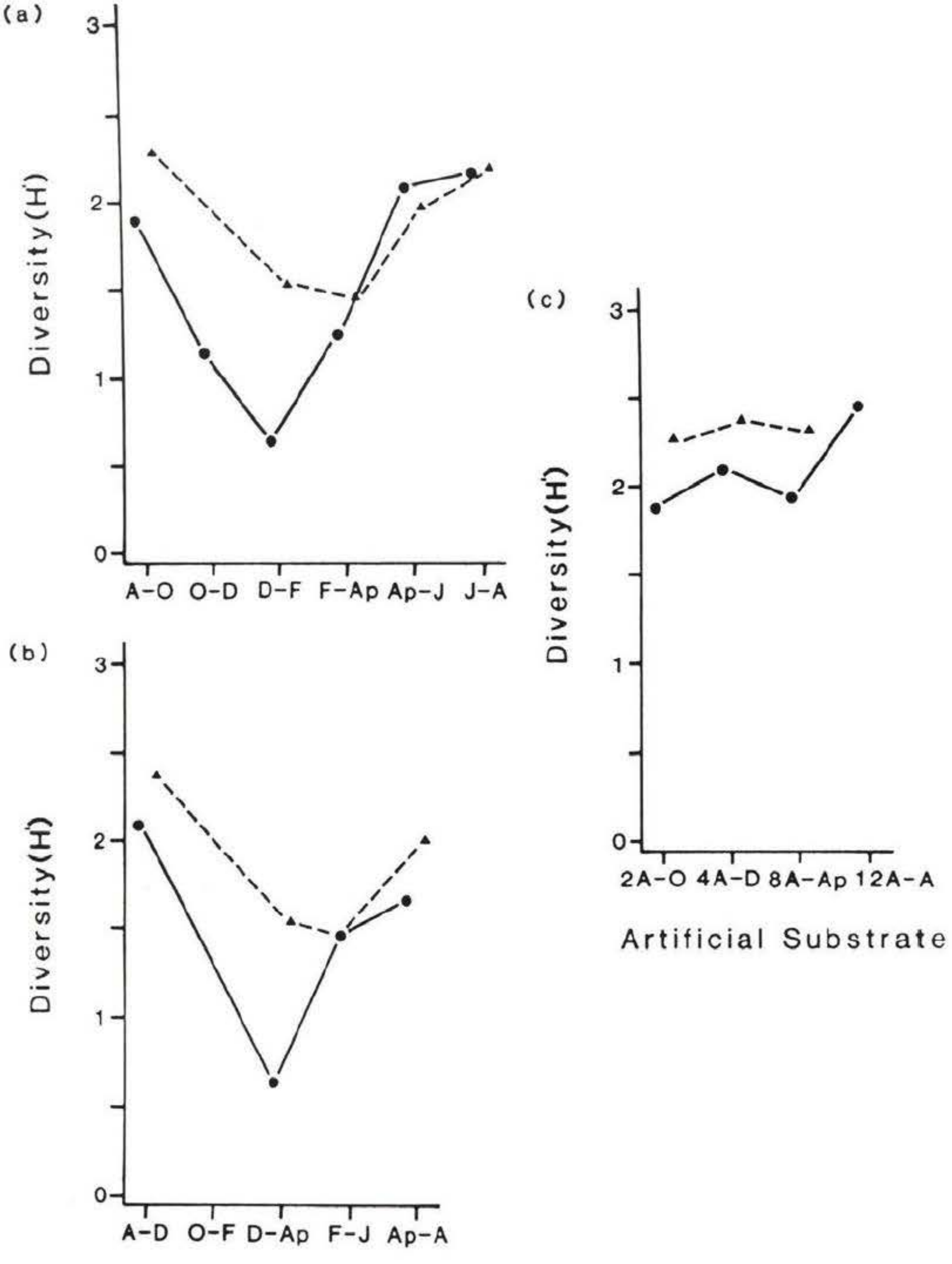
The Shannon-Wiener diversity index (H') was generally higher in 2 and 4 month control substrates than in corresponding tailings (Figs. 10a,b). Seasonal fluctuations in diversity resembled the predominant seasonal pattern found in abundance and richness. Typically, diversity was high in the fall, declined over winter and rose again in summer.

In the four experimental units started in August, diversity was consistently higher in controls than in tailings (Fig. 10c). Diversity showed little change as community age increased from 2 to 8 months. However, an increase did occur from the 8 to 12 month tailing substrates. This trend in diversity over the August time series closely resembles that shown by the number of taxa.

Figure 10: Shannon-Wiener diversity (H') of artificial substrate communities.

Tailing substrates-circles, control substrates-triangles. Points are means of two replicates, except where a replicate was lost (Table 1) then n=6. See table 1 for artificial substrate codes.

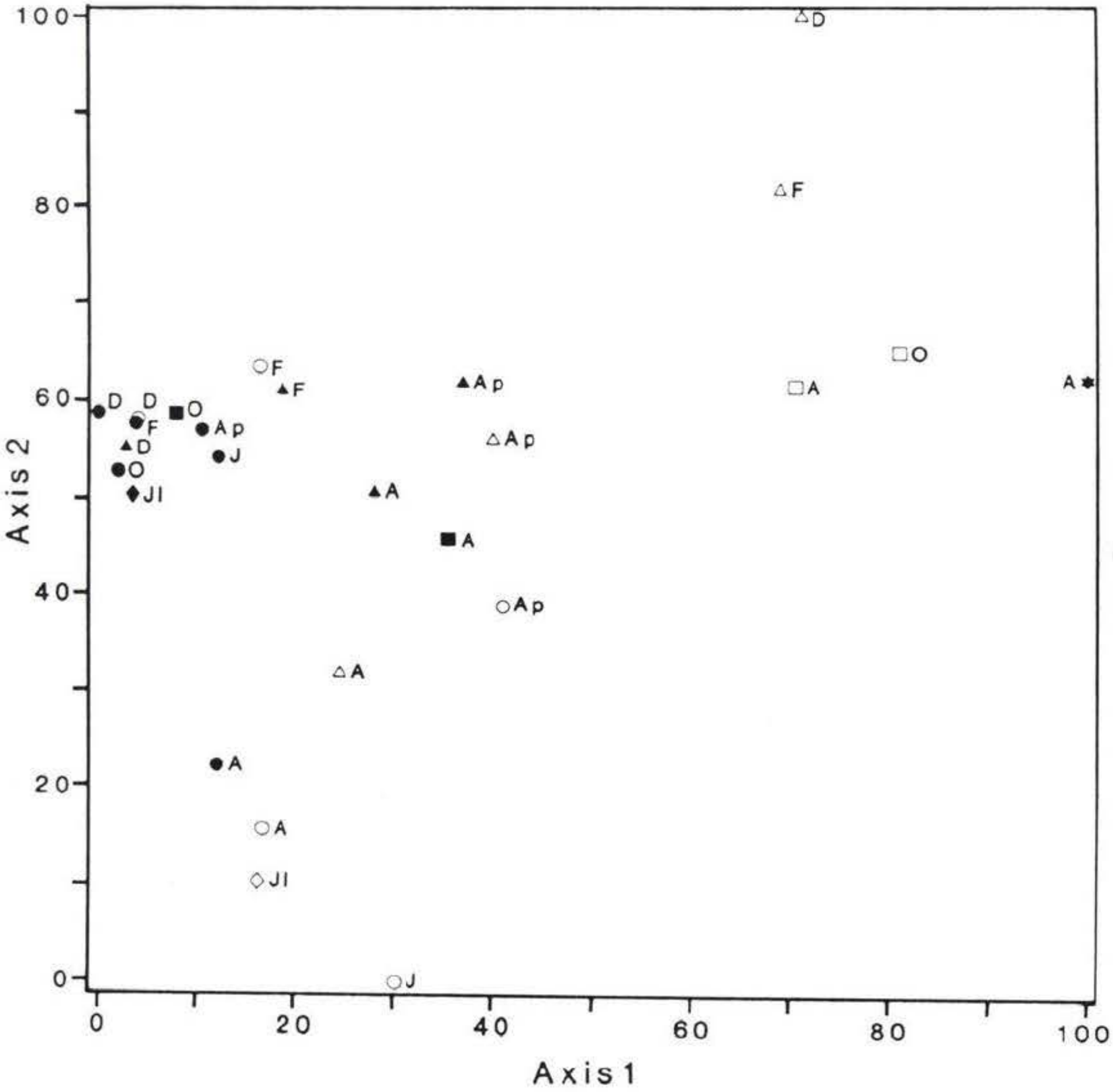
(a) 2 month artificial substrates.
(b) 4 month artificial substrates.
(c) Artificial substrates initiated in August 1982.


(a)
3
2
1
0
Diversity(H')
A-O
O-D
D-F
F-Ap
Ap-J
J-A
(b)
3
2
1
0
Diversity(H')
A-D
O-F
D-Ap
F-J
Ap-A
Artificial Substrate
(c)
3
2
1
0
Diversity(H')
2A-O
4A-D
8A-Ap
12A-A
Artificial Substrate

VI. The Effect of Exposure Length, Substrate Type, and Season on Taxonomic Composition and Taxa Abundances

The ordination technique, Non-Centred Principal Components Analysis (PCA), was used to elucidate the effects of exposure length, substrate type, and season on the taxonomic composition and taxa abundances in artificial substrates. A PCA of all artificial substrates (replicates pooled) accounted for 75% of the total variance with the first two axes. The exposure length, substrate, and seasonal effects have acted together to position artificial substrates on the ordination axes; therefore the separate influences of the three effects are difficult to isolate (Fig. 11). However, some general trends are apparent in figure 11. Control and tailing containers do not form two distinct groups, instead they are interspersed among each other. This suggests that similar taxonomic assemblages colonized control and tailing substrates.

In sets of containers initiated in the same month and of the same substrate type, the 2 month container usually scores lower on axis one than the 4 month, and the 4 month container scores lower than the 8 month. Thus, this first dimension shows that the taxonomic composition and/or taxa abundances in artificial substrates change as the exposure length increases. The number of individuals and taxa associated with artificial substrates also tend to increase as exposure length rises, and therefore also increase as substrate distance along axis one rises. Ordination scores, on axis one, correlate significantly with the number of individuals ($r = 0.82$) and taxa ($r = 0.79$). A substrate effect is evident on axis one. Tailing containers are almost always positioned lower on the first axis than their controls (Fig. 11).


Axis 2
Axis 1
0
20
40
60
80
100
0
20
40
60
80
100
D
D
F
O
Ap
J
D
O
JI
F
F
A
Ap
A
A
Ap
Ap
A
A
A
JI
J
D
F
A
O
A

A seasonal effect is demonstrated in figure 11 by the spatial separation of containers of identical substrate type and exposure length, but initiated in different months. Tailing and control 2 month, and 4 month tailing substrates, all display similar seasonal arrangements; substrates initiated in August, February, April, and June are situated further along axis one than substrates started in October and December. Containers from the above group, started from October to February, form a group on the left side of figure 11, indicating that they are similar. The seasonal arrangement of 4 month controls differs from that displayed by the other container types. Control 4 month substrates initiated in December and February are further along axis one than those started in August and April.

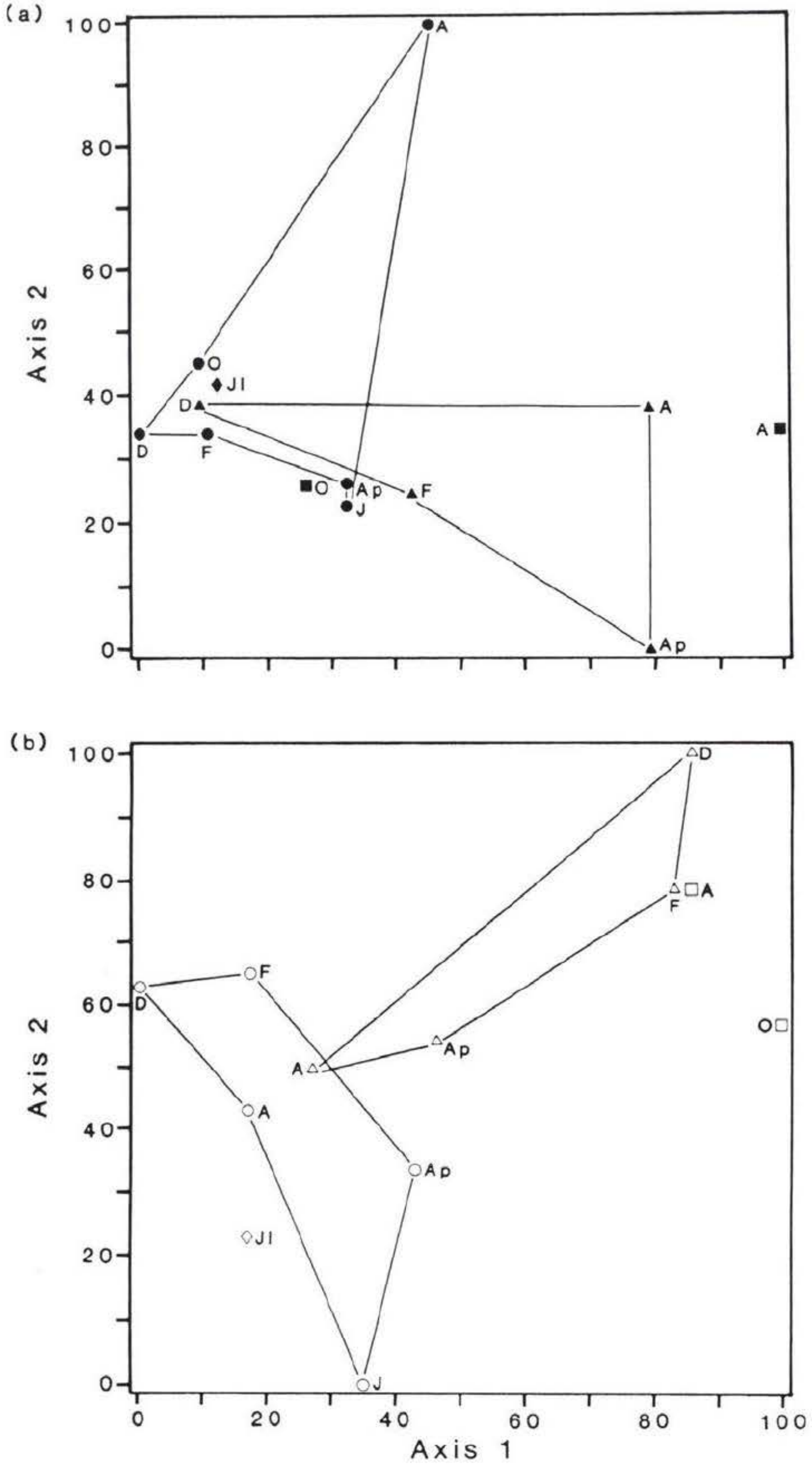
A. Exposure Length and Seasonal Effect

Control and tailing artificial substrates were ordinated separately to allow examination of the effects of exposure length and season. A preliminary PCA of tailing substrates found the T12A-A container to be an outlier, which was compressing distances between other substrates. Therefore, the T12A-A container was removed and the PCA repeated. In the resulting ordination 83% of the total variance was accounted for in the first two axes. Pairs of 2, 4, and 8 month substrates initiated concurrently, all show the two month substrate situated lower on axis one than the 4 month, and the 4 month situated lower than the 8 month (Fig. 12a). As in the PCA of all substrates (Fig. 11), the first dimension of the tailing PCA is showing a uni-directional temporal change in the taxonomic composition and/or taxa abundances in artificial substrates as their exposure length increases.

Figure 12: Non-centred principal components analysis of tailing and control artificial substrate communities.

See figure 11 for legend. Lines connect artificial substrates of equal exposure length in seasonal sequence.

(a) Tailing artificial substrates.
(b) Control artificial substrates


(a)
Axis 2
100
80
60
40
20
0
A
O
JI
D
A
A
D
F
O
Ap
F
J
Ap
(b)
Axis 2
100
80
60
40
20
0
D
F
A
F
D
O
A
Ap
A
Ap
JI
J
0
20
40
60
80
100
Axis 1

The similarity between paired 2 and 4 month substrates fluctuates seasonally. 2 and 4 month substrates initiated in December are closer to each other than are the corresponding pairs started in August, February, and April.

Substrate scores on axis one of the tailing PCA correlate significantly with the number of individuals ($r = 0.91$) and taxa ($r = 0.92$) in tailing containers. Generally, exposure length and seasonal effects displayed in the tailing PCA are similar to those evident in abundance and richness data. However, the PCA separates the 2 and 4 month substrates initiated in August (Fig. 12a), although they supported similar numbers of individuals and taxa (Figs. 7a,c). Thus, the separation is based on a difference in taxonomic composition, and/or abundances of individual taxa. The T2A-O substrate contained approximately twice the number of amphipods and half the number of polychaetes than did T4A-D.

Aside from the above exception, abundance and richness measures in tailing substrates support the findings of the tailing PCA by showing that: (1) 2 month substrates usually supported lower numbers of individuals and taxa than the corresponding 4 month substrate; and (2) the similarity between 2 and 4 month containers fluctuates seasonally.

A PCA of control artificial substrates accounted for 76% of the total variance with the first two axes. The effect of exposure length on positions of control substrates is similar to that evident in the tailing PCA. In all groups of 2, 4, and 8 month containers initiated concurrently, the 2 month container is located lower on axis one than the 4 month, and the 4 month is located lower than the 8 month (Fig. 12b). Again the first axis is displaying a uni-directional temporal change in taxonomic composition and/or taxa abundances with exposure length.

The distance between 2 and 4 month containers, started together, fluctuates seasonally (Fig. 12b). Maximum distances occur between substrates initiated in December and February, while substrates started in August and April are closer together. This pattern is the reverse of that displayed in the tailing ordination (Fig. 12a).

The control PCA demonstrates that the C1J1-A substrate is more similar to most 2 month substrates, than to 4 month substrates (Fig. 12b). Eight month containers are located high on axis one of the control PCA, close to the 4 month substrates that supported the highest numbers of individuals and taxa (Figs. 7b,d).

Substrate scores on the first axis of the control PCA correlate significantly with measures of abundance in control containers ($r = 0.65$), but not with richness ($r = 0.39$). Over the sampling period, 4 month controls showed little change in numbers of taxa (Fig. 7d), but the control PCA displays large distances between these substrates (Fig. 12b). The disagreement between these two results may explain the non-significant correlation between richness and scores on axis one.

The exposure length effects demonstrated in abundance and richness data do not always concur with the exposure length effects evident in the control PCA. In the PCA, 4 month substrates are further along axis one than are corresponding 2 month substrates (Fig. 12b). However, only the 4 month containers initiated in December and February supported higher numbers of individuals and taxa than their 2 month counterparts (Figs. 7b,d). Measures of abundance and richness in control substrates do corroborate the other findings of the control PCA by showing: (1) seasonal fluctuation in differences between 2 and 4 month containers; and

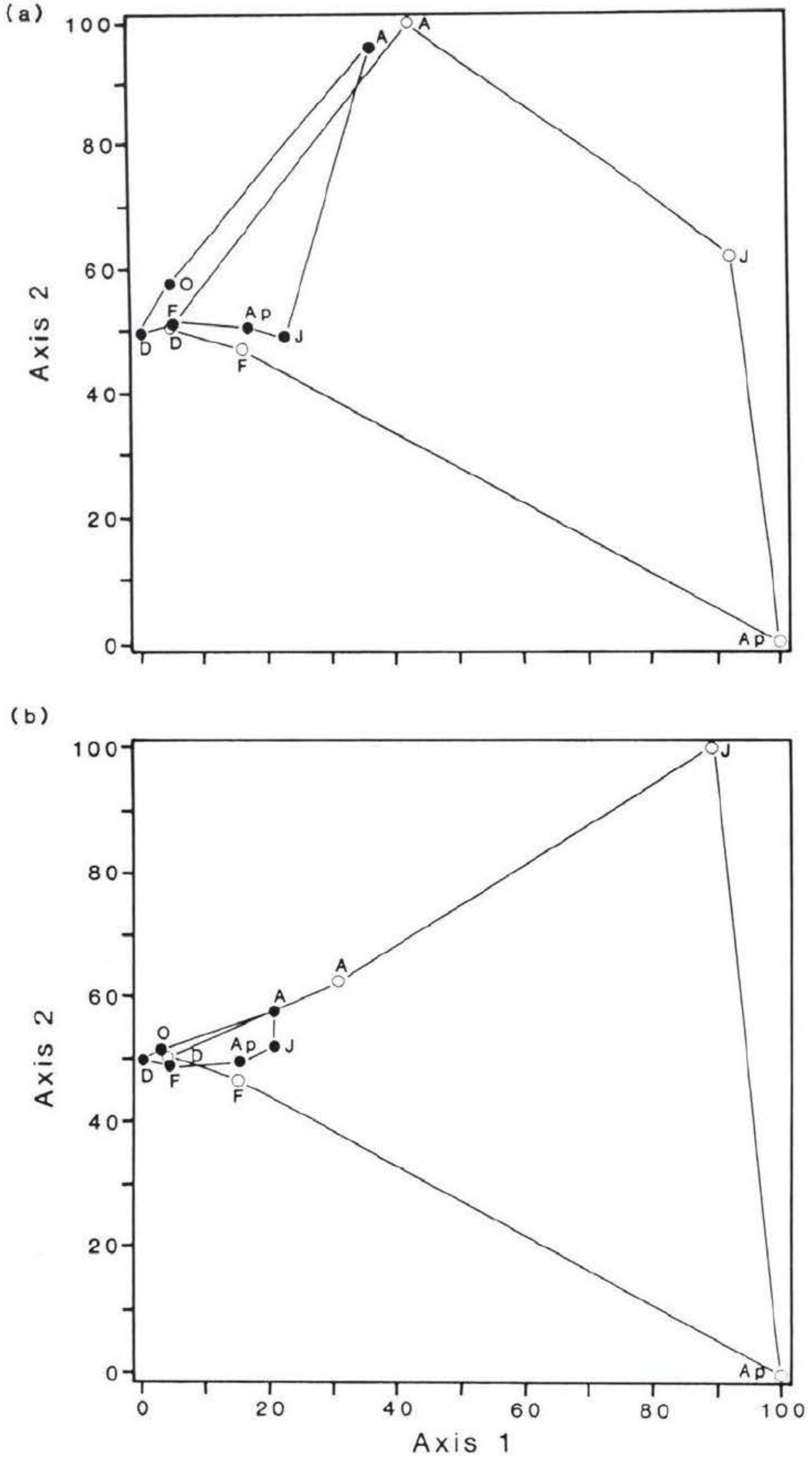
(2) that the number of individuals and taxa in C8A-Ap and C80-J are similar to those in C4D-Ap and C4F-J.

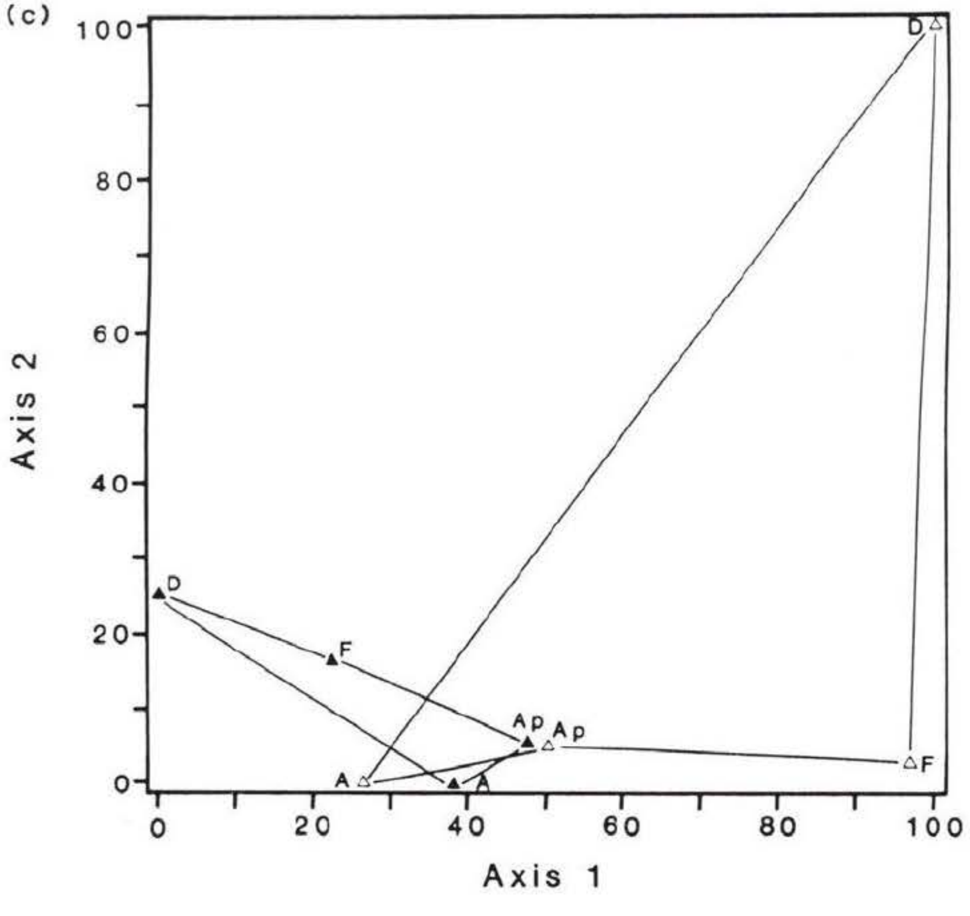
B. Substrate and Season Effect

To examine the effects of substrate type and season, 2 and 4 month artificial substrates were ordinated separately. The resulting 2 month PCA accounted for 72% of the total variance in the first two axes. In all instances, tailing substrates are situated lower on axis one than their controls (Fig. 13a). The similarity between 2 month tailing substrates and corresponding controls fluctuates seasonally. Tailing containers started from August to February are positioned closer to their controls than are the tailing substrates initiated in April and June (Fig. 13a).

The arrangement of substrates in the 2 month ordination shows tailings and controls following similar seasonal patterns (Fig. 13a). Fall substrates (2A-0) are positioned higher on axis one than winter substrates (20-D, 2D-F). Distance along axis one generally increases consecutively in containers initiated from February to June. The area delineated by connecting control substrates is greater than that defined by tailings (Fig. 13a). This demonstrates that control containers showed wider seasonal fluctuations in similarity than did tailings.

Substrate scores on axis one of the 2 month PCA correlate significantly with abundance ($r = 0.95$) and richness in artificial substrates ($r = 0.94$). This indicates that the effects of substrate type and season, displayed in the first axis of the 2 month ordination, are similar to those evident in the number of individuals and taxa. Measures of abundance and richness in artificial substrates (Figs. 7 and 8)


(a)
100
80
60
40
20
0
Axis 2
A
A
J
O
F
Ap
J
D
D
F
Ap
(b)
100
80
60
40
20
0
Axis 2
J
A
A
O
Ap
J
D
D
F
F
Ap
0
20
40
60
80
100
Axis 1


(c)
D
D
F
Ap
Ap
A
A
F
Axis 2
Axis 1
0
20
40
60
80
100
0
20
40
60
80
100

corroborate the ordination results by showing: (1) that tailing substrates supported significantly lower numbers of individuals and taxa than controls (Table 6); (2) the presence of seasonal fluxes in the differences between tailings and controls, with maximum differences in spring and summer; (3) a similar seasonal pattern in tailings and controls, of high fall values followed by winter declines and spring-summer increases; (4) that winter controls are closer to tailing substrates than to controls started in spring and summer; and, (5) greater seasonal fluctuations occurring within controls than within tailings.

In the 2 month PCA, the 2A-0 substrates score high on axis two and are thus separated from all other substrates (Fig. 13a). However, abundance and richness data do not distinguish the 2A-0 substrates from all other 2 month containers (Figs. 8a,b). Therefore, the PCA is isolating the 2A-O substrates on the basis of their taxonomic composition, and/or abundances of individual taxa. Amphipod numbers and their relative abundances reached maxima in the 2A-O substrates (Figs. 4a,b and 6a,b). A PCA of 2 month containers, with amphipods deleted from the analysis, moved the 2A-0 substrates down axis one close to the tailing substrates and winter controls (Fig. 13b). This suggests that the high amphipod numbers in the 2A-O substrates are responsible for the segregation of these substrates in the 2 month PCA.

A PCA of 4 month artificial substrates accounted for 90% of the total variance with the first two axes. Tailing substrates and their controls are arranged as they were in the 2 month PCA (Fig. 13a); tailings are usually located lower on axis one than their controls (Fig. 13c). The similarity between tailing containers and corresponding controls fluctuates seasonally in the 4 month PCA (Fig. 13c). Maximum differences between the two substrate types occur in containers initiated in December and February. This pattern is the reverse of that found in the 2 month ordination (Fig. 13a).

Substrate positions in the 4 month PCA indicate that tailing and control containers followed different seasonal patterns (Fig. 13c). Four month tailing substrates display the seasonal trend that is evident in the 2 month PCA (Fig. 13a) of containers initiated in August and April, positioned higher on axis one than those started in December and February. The arrangement of 4 month control substrates diverges from this seasonal pattern, as control substrates initiated in December and February are situated further along axis one than those started in August and April (Fig. 13c).

In the 4 month PCA, seasonal fluctuations within controls are greater than those within tailings (Fig. 13c). A wider fluctuation within controls was also evident in the 2 month PCA (Fig. 13a). The number of individuals in 4 month containers shows approximately the same amount of seasonal change in tailings and controls, however values attained in controls were much higher than in tailings (Figs. 8b,d). The number of taxa changed less in 4 month controls than in tailings (Figs. 8b,d). The C4D-Ap container is the only control that scores high on axis two (Fig. 13c), and thus is the main cause of the area defined by controls being greater than that defined by tailings. Abundance in the C4D-Ap substrate was high and the population contained an unusually high population of sabellids (Fig. 5d), which may explain C4D-Ap's dissimilarity to other controls.

The number of individuals in 4 month substrates correlates significantly ($r = 0.78$) with substrate scores on axis one of the 4 month PCA. However, the correlation between the number of taxa and scores on axis one is non-significant ($r = 0.32$). A non-significant correlation with richness was also noted in the control ordination, and was attributed to the lack of concordance between numbers of taxa in 4 month control containers and their position on axis one. This may also explain the non-significant correlation in the 4 month ordination where again 4 month control substrates are spaced out along axis one, while richness in these containers shows only slight fluctuations (Figs. 7b,d).

Apart from the above discrepancy, abundance and richness in 4 month containers reflect the substrate and seasonal effects demonstrated by the 4 month ordination. Measures of abundance and richness in 4 month artificial substrates (Figs. 8b,d) support the ordination results by demonstrating: (1) that tailing substrates contained lower numbers of individuals and taxa than controls, although this difference is not always significant; (2) that the difference between tailings and controls fluctuates seasonally, with maxima occurring in substrates initiated during winter; and, (3) tailing and control containers followed two different seasonal patterns.

The 2 and 4 month PCA's demonstrate seasonal patterns within tailing and control substrates (Figs. 13a,c). These seasonal patterns are the same as those evident in the tailing and control PCAs (Figs. 12a,b).

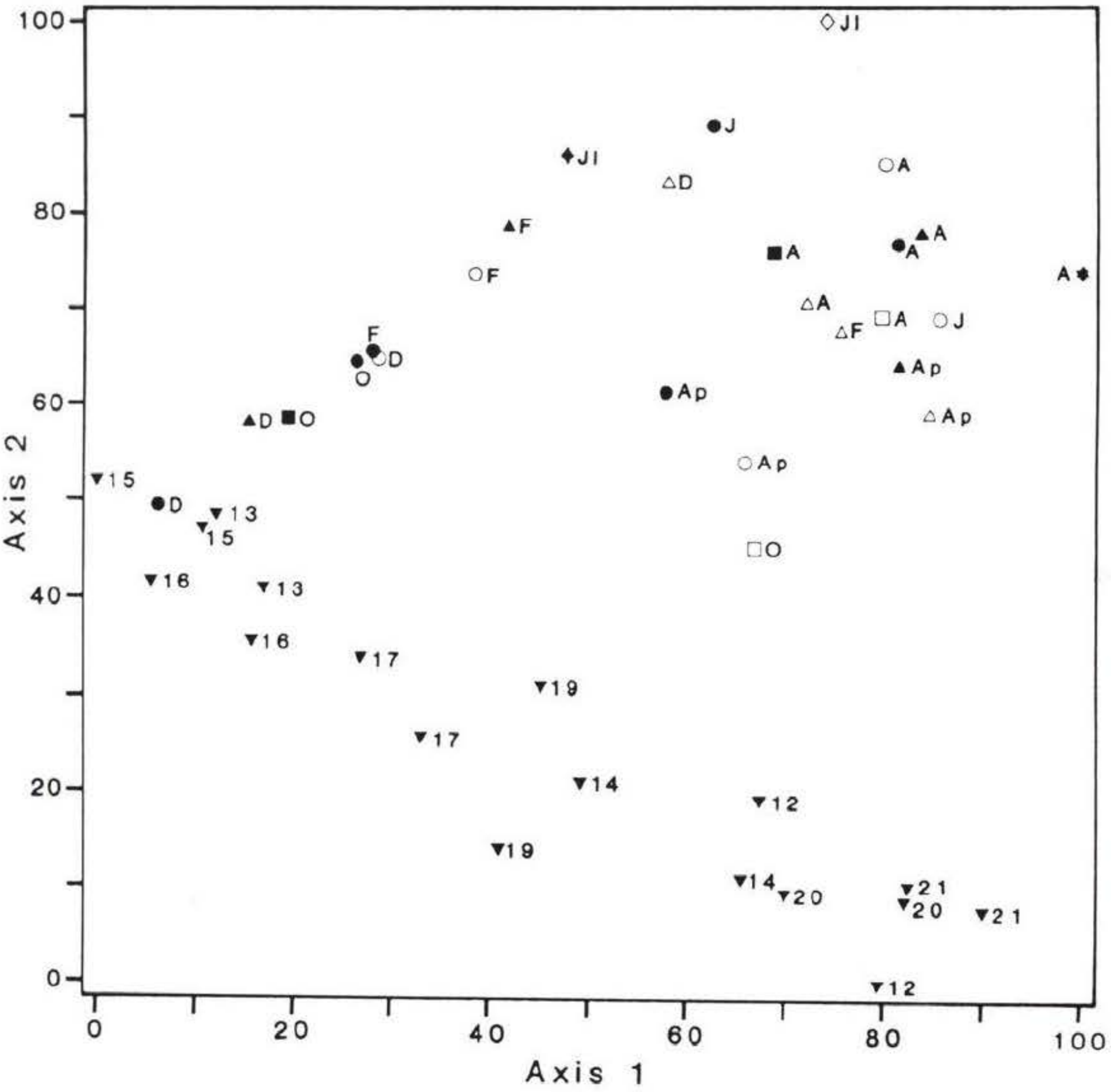
VII. Comparison of Taxonomic Assemblages in Artificial Substrates and Island Copper Mine's Benthic Samples

Island Copper-Utah Mines annually collects benthic samples from Rupert Inlet in September. The 1982 and 1983 samples from stations 12 to 21 (Fig. 1) were compared to artificial substrate samples from this study in an attempt to determine the state of benthic community development in Rupert Inlet. The Rupert Inlet benthic fauna was similar to that of artificial substrates; 71% of the taxa present in Rupert Inlet colonized artificial substrates.

A PCA including all artificial substrates and the Rupert Inlet samples is displayed in figure 14. This ordination was based on taxa presence-absence. Sixty-one percent of the total variance was accounted for by the first two axes. Artificial substrates are positioned in the upper half of the diagram, and are spread along axis one from T2D-F to T12A-A. The arrangement of substrates within this group diverges from that seen when artificial substrates were ordinated separately (Fig. 11); however, the same general trends are apparent. In groups of containers initiated concurrently and of the same substrate type, the 2 month container usually scores lower on axis one than the 4 month, and the 4 month scores lower than the 8 month (Fig. 14). Thus, axis one is displaying a uni-directional change in taxonomic composition with time. Tailing substrates are generally located lower on axis one than their controls. Substrates initiated from October to February score low on axis one, and richness generally increases as substrate scores on axis one increase.

Figure 14: Non-centred principal components analysis of the communities inhabiting artificial substrates and Island Copper Mine's 1982 and 83 benthic stations 12-21.

Numbers-benthic station. See figure 11 for legend for artificial substrates.


Axis 2
Axis 1
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40
60
80
100
JI
J
JI
D
A
F
A
A
A
A
F
A
A
J
F
A
F
D
O
Ap
D
O
Ap
15
D
13
15
Ap
O
16
13
16
17
19
17
14
12
19
14
20
21
20
21
12

The majority of Rupert Inlet samples are restricted to the lower half of the PCA, and are thus separated from the artificial substrates (Fig. 14). Rupert Inlet samples are spaced along the first axis and richness generally increases as the distance along axis one rises. Distance along axis one also correlates with distance from the tailing outfall and turbidity current. The segregation of Rupert Inlet samples from artificial substrates breaks down on the left side of figure 14, where Rupert Inlet samples 13, 15 and 16 are close to the artificial substrates that experienced the least colonization. Therefore, communities in samples 13, 15 and 16 are similar to those found in artificial substrates during the initial stages of colonization.

DISCUSSION

I. Comparison of Tailing and Control Artificial Substrates

Mine tailings released into Rupert Inlet by Island Copper mine contain high levels of certain heavy metals (ie. mean dissolved copper and molybdenum concentrations in 1984 were 11.4 and 187.5 ug L^{-1} respectively (Island Copper, 1985)), and chemicals added during the milling and discharge processes (Evans *et al.*, 1979). To establish that any differences between the colonization of these tailings and the control substrate were caused by the chemical content of tailings, it was essential that the control mimic tailings as closely as possible, without containing the high levels of heavy metals or other chemicals added to the tailings. The control substrate used in this study was quarried-marble sand. It was selected primarily because its median particle diameter and degree of sorting approximated that of the tailings. Replication of sediment particle structure was emphasized, as numerous studies have correlated distribution of benthic organisms to changes in sediment particle size, degree of sorting, and sediment type (Sanders, 1958; Boaden, 1962; Richter and Sarnthein, 1977; Risk and Tunnicliffe, 1978).

Average median particle diameter of tailing and control substrates differed by 0.05 mm, and both substrates were well sorted. It is not known what effect this shift in particle size would have on benthic communities. Current information suggests that individual macrobenthic species are able to inhabit much wider particle size ranges. Wilson (1948) reports *Ophelina bicornis* Savigny predominantly occurring in sands ranging from 0.20 - 0.45 mm in diameter. *Protodrilus rubropharyngens* (Jägersten) larvae prefer particles of 0.5 - 1.0 mm in diameter (Gray, 1967), and larvae of *Polydora ciliata* (Johnston) will metamorphose on any substratum with grains finer than 0.25 mm in diameter (Kiseleva, 1967). The particle size ranges preferred by these species are at least an order of magnitude above 0.05 mm. Therefore, the difference in particle diameter between tailing and control substrates used in this study probably does not substantially alter macrobenthic colonization.

Sediment pH may affect benthic colonization. Marble sand is composed of limestone which is alkaline in solution. Island Copper's tailings are primarily quartz and feldspar; however, a lime coagulant is added upon discharge, which elevates tailing pH (Pedersen, 1983). In addition the pH of both substrates in seawater was similar. pH was, therefore, considered constant between tailing and control substrates.

The control substrate adequately duplicated the physical sediment structure and pH of tailings. In contrast, chemical composition of the control differed from tailings, as the control substrate contained low levels of heavy metals, and had not been contaminated by chemical additions. This difference in chemical composition was, therefore, the major factor that could cause differences between the colonization of tailing and control artificial substrates.

Although marble sand was considered a valid control, physical and chemical processes acting during the exposure period could have changed the physical and/

or chemical nature of either substrate. Scouring by currents and sedimentation may have altered the particle size of artificial substrates. Measured particle size change throughout exposure was so small that these factors appear not to have been influential. Currents, sedimentation, and compaction could have changed substrate depth in containers. Decreases in substrate depth were recorded; however the amount of decrease showed no consistent difference between tailing and control substrates, indicating that factors causing the change were not acting differently on substrate types.

All artificial substrates received sediment from the water column. In this deposited material, copper and molybdenum concentrations were higher than those found in the sediments of Holberg Inlet and Quatsino Sound that do not receive tailing deposits, and lower than those in regions of heavy tailing deposition (Island Copper, 1976-1985). This suggests that suspended solids in Rupert Inlet are a mixture of tailings and natural terrestrial runoff. Sedimentation of these solids elevated levels of most heavy metals in control substrates, while probably decreasing concentrations of some metals in tailing substrates. Given sufficient time, the chemical composition of the two substrates would probably converge. This does not appear to be a problem within the time frame of my study; despite sedimentation, heavy metal levels in controls exposed for 8 months were substantially lower than those in 8 and 12 month tailings. In general, changes that occurred in substrates throughout exposure, were not deemed sufficient to invalidate the control. However, the changes in box contents indicates that the technique has time limitations which may become more severe in more turbid environments.

II. Method of Recruitment - Adult or Larval

In terrestrial environments adult migration is often the major method of colonization of new habitats. Colonization of marine soft bottom environments is usually assumed to occur primarily through larval settlement (Thorson, 1966; McCall, 1977; Santos and Simon, 1980). However, the importance of adult migration to the colonization of marine soft bottoms has not been established. Dean (1978) found six species of adult polychaetes swimming in the plankton at night, and hypothesized that this behaviour may be a method of dispersal. It also seems possible that motile adults could crawl on or through sediment to colonize an area. All previous subtidal soft artificial substrate colonization studies have precluded immigration by crawling infaunal benthos, by completely enclosing all but the top of the artificial substrate and then placing it on or above the sediment surface (McCall, 1977; Grassle, 1977; Richter and Sarnthein, 1977; Desbruyères *et al.*, 1980; Arntz and Rumohr, 1982; Watzin,1983; Levin and Smith, 1984). If artificial substrates are to be used to study the natural colonization of soft substrates, access to the substrates for crawling adults must be provided until such time as it has been demonstrated that this method of colonization does not occur.

Artificial substrate containers used in this study were left open at one end to allow adult immigration. Sediment slumped out of the open end, thus forming a bridge from artificial substrates to the surrounding sediment. Concentrations of organisms near the open end, higher than those near the closed end, would indicate that adults were crawling into artificial substrates. No difference in concentration was found. In addition, very few large individuals were encountered in samples. This suggests that adults swimming or crawling into substrates did not play an important role in the colonization of mine tailings or the control substrate. However, amphipods must have entered substrates as juveniles or adults, as they have no larval stage. Tailings and the control contained low levels of organic matter, which possibly rendered them unattractive to motile adults. Adult immigration may be more frequent in the colonization of substrates high in organics.

Santos and Simon (1980) also conclude that colonization of their soft artificial substrates was primarily through larval settlement. However, their substrates were placed 0.5 m above the natural bottom, which would have prevented adults from crawling into the containers. In contrast, Bonsdorff (1980) demonstrated that adult *Macoma baltica (L.)* were able to immigrate into defaunated areas. Probably, the importance of adult migration in the colonization of soft bottom environments is related to a variety of factors, such as the location of the sediment, its chemical composition, and the species involved.

III. Faunal Description

The major faunal groups found inhabiting artificial substrates - polychaetes, amphipods, gastropods, and pelecypods - also predominate in the surrounding sediments of Rupert Inlet (Island Copper, 1976-1985). These sorts of soft bottom communities are common in the north-west Pacific (Lie, 1965; Levings *et al.*, 1983). Generally, polychaetes numerically dominated artificial substrate faunas. The relative importance of the other groups fluctuated with substrate type, exposure length, and season. This pattern of colonization is not unique. Numerous authors have reported polychaetes to be the dominant colonizers in the early stages of macrobenthic soft bottom colonization (Rhoads *et al.*, 1977; Simon and Dauer, 1977; McCall, 1977, 1978; Bonsdorff, 1980; Arntz and Rumohr, 1982), and Rosenberg (1976) found polychaetes dominated the early stages of recovery following pollution abatement.

Simon and Dauer (1977) relate the initial dominance of polychaetes in their study to the year round reproduction of some polychaetes and their remarkable dispersal abilities. Recruitment of polychaetes into artificial substrates dropped sharply over the winter, indicating that in Rupert Inlet there are seasonal fluctuations in reproduction or larval availability of polychaetes. However, polychaetes usually dominated winter substrates, so despite seasonal fluctuations in abundance, polychaetes may dominate the larval component of the plankton year-round. This could explain their continual dominance of artificial substrates.

Alternatively, all groups may be abundant in the plankton. Larval settlement is probably not random, as many invertebrate larvae have the capacity to actively seek, and settle on, a particular substrate (Crisp, 1974). Thus, polychaete dominance may result from some polychaetes choosing to settle in unoccupied substrates, while other taxa select against settlement in such habitats. Dispersal abilities of some polychaetes may also be superior to, or more rapid than, that of other groups. This would allow polychaetes to quickly locate and exploit new substrates. Conversely, initial recruitment may not be dominated by polychaetes. Instead the polychaete survival rate may be higher than that for other groups, or polychaetes may have higher growth rates so are the major taxa retained by the relatively course 0.5 mm and 1.0 mm sieves typically used in sampling macrobenthos.

Seven of the ten abundant taxa in artificial substrates were polychaetes. A search among these seven for a successional sequence of abundant taxa revealed no clear pattern. I define succession following Gallager *et al.*, (1983) as the temporal pattern of change in the taxonomic composition or abundances of individual taxa in a community. The most abundant taxon was the genus *Lumbrineris* (principally *L. luti* (Berkely and Berkely)) whose members were present in all but 4 artificial substrates. The high numbers and ubiquitous nature of *Lumbrineris* suggest that it may be an opportunist (*sensu* Grassle and Grassle, 1974) in the colonization process. However, such a classification would require *Lumbrineris* populations to decline as the community aged. This did not occur, even after 12 months of community development; thus no clear conclusion on the colonization strategy of this taxon can be drawn.

Winieki and Burrell (1985), in their study of artificial substrate colonization in an Alaskan fiord, ranked *L. luti* among the five dominant species and recovered *L. luti* from all artificial substrates. Their corroboration of my findings suggests that colonization and dominance of new substrates by *L. luti* may be common in north Pacific fiords.

Lumbrineris species have been variously described as herbivores, deposit feeders, and carnivores (Fauchald and Jumars, 1979). Thus, it may be that their feeding habits are unspecialized, and they are omnivorous. This would allow them to use a wide diversity of food resources, which would facilitate their exploitation of new habitats.

Capitellid polychaetes, particularly members of the *Capitella* species complex have often been reported to be opportunistic colonizers of benthic habitats following disturbances (Grassle and Grassle, 1974; Rosenberg, 1976; Wolff *et al.*, 1977; McCall, 1978; Pearson *et al.*, 1982). Numbers of Capitellidae in artificial substrates were generally low, except in one 2 month and in the 12 month container. Therefore, members of the Capitellidae, including *Capitella* sp. did not colonize artificial substrates in an opportunistic manner.

Tailings and control substrates used in this study contained almost no organic matter. Studies that describe members of the *Capitella* species complex as opportunistic species (Grassle and Grassle, 1974; Rosenberg, 1976; Wolff *et al.*, 1977; McCall, 1978; Pearson *et al.*, 1982) have monitored succession on organically enriched sediment (e.g. sediment defaunated by freezing or affected by organic pollution). In contrast, Arntz and Rumohr (1982) followed colonization of a sediment low in organic content. My findings agree with Arntz and Rumohr's data. They do not report *Capitella* sp. as an opportunistic colonizer. As capitellids are considered deposit feeders (Fauchald and Jumars, 1979), they likely prefer substrates high in organic matter. This preference may discourage capitellid colonization of sediments consisting mainly of inorganic material - primary succession (*sensu* Odum, 1971). Instead, their opportunistic colonization may be restricted to areas high in organic matter - secondary succession (*sensu* Odum, 1971).

Polychaete dominance in the initial stages of soft substrate macrobenthic colonization is a widespread but not universal phenomenon. Polychaetes were replaced as dominants by amphipods and gastropods in a few tailing artificial substrates exposed during fall and winter. Winieki and Burrell (1985) also found crustaceans often replacing polychaetes as initial dominants in artificial substrates; however Arntz and Rumohr (1982) report crustacean dominance in the third year of artificial substrate colonization. This diverse class probably plays many roles in the colonization sequence, and perhaps must be broken into finer divisions before meaningful patterns will emerge. Nevertheless, most studies have not shown crustaceans attaining dominance with time. Rather, many authors report that as communities age, the percent of pelecypods increases and they come to dominate, or co-dominate with polychaetes and less frequently amphipods (Rhoads *et al.*, 1977; Simon and Dauer, 1977; McCall, 1977, 1978; Bonsdorff, 1980; Arntz and Rumohr, 1982).

The percentage of pelecypods in artificial substrates was generally low, even after 12 months of development. However, pelecypod numbers did increase with community age until 8 months in substrates initiated in August. This may indicate that after 8 to 12 months of exposure, the artificial substrate communities in Rupert Inlet were still in the initial stages of development. If this is the case, given sufficient time, the percent of pelecypods may increase and dominance may shift away from polychaetes, producing taxonomic assemblages similar to those described by the above authors.

While it is interesting to seek out general patterns in benthic colonization, it should not be viewed as proceeding along one characteristic successional path, unaffected by environmental parameters. The relative abundances of the four major faunal groups and the numbers of the ten abundant taxa, within 2, 4, and 8 month artificial substrates, varied with substrate type and season. Because of these variations, no one successional sequence of faunal groups or taxa occurred in these artificial substrates. Benthic colonization and succession have previously been reported to vary with substrate type (Richter and Sarnthein, 1977; Zajac and Whitlatch, 1982a) and season (Arntz and Rumohr, 1982; Zajac and Whitlatch 1982a,b; Winieki and Burrell, 1985). Therefore, as Zajac and Whitlatch (1982b) suggest, benthic colonization, at least initially, may primarily be influenced by environmental parameters such as season, and not follow a rigid sequence of taxa.

Substrate type, at times, appeared to influence the identity of the dominant group in artificial substrates. Throughout the year control substrates were dominated by polychaetes. In contrast, on four occasions from July to April, tailing substrates were dominated by amphipods or gastropods. This difference in dominance between tailings and controls, was not caused by tailings containing higher numbers of amphipods and gastropods than controls. Instead, the tailings supported lower numbers of polychaetes. Polychaete numbers in all tailing artificial substrates were lower than in corresponding controls. This decrease in polychaete colonization of tailings, seems to render the identity of the dominant group in tailings less stable than that in controls. As will be discussed later, the lower numbers of polychaetes colonizing tailing substrates may indicate a slower rate of colonization in tailings than in controls.

The major seasonal event common to both substrate types was the late summer and fall increase in amphipods, primarily *Protomedia articulata* in the 1J1-A and 2A-0 substrates. This elevation in amphipod numbers subsided as the community aged; numbers of amphipods in 4 and 8 month substrates initiated with the 2A-0 substrates, dropped from the 2 month levels. *P. articulata* appeared to be acting as an opportunist only in the fall, when it was able to rapidly colonize new substrates. Typical of an opportunist, their numbers declined as the community aged. This decline may result from emigration or mortality due to competition or predation. If some species act as opportunists in only certain seasons, the classification of a species as an overall opportunist must be accompanied by a year-round study of its colonization potential.

As previously discussed, when artificial substrate colonization is examined in terms of major faunal groups or abundant taxa, variation occurs with substrate type and season; hence no one successional sequence emerges. However, colonization may follow a clearer successional pattern if the fauna is divided into ecological rather than taxonomic groups. In other words, a succession of ecological groups may occur in the colonization process, although the taxonomic composition within these groups fluctuates.

Examination of ecological groups in artificial substrates was restricted to the dominant faunal group; the polychaetes. Ecological groups were defined as the feeding modes constructed by Fauchald and Jumars (1979); herbivores, surface deposit feeders, subsurface deposit feeders, filter feeders, and carnivores. An undefined mode was added for *Lumbrineris* sp. as they could not be placed in any of the above groups. A note of caution on the validity of these ecological groups comes from Dauer (1984), who found them no better than random classifications when correlating polychaete distributions with some environmental variables.

Further, Fauchald and Jumars (1979) classify polychaetes into one or more feeding modes at the family level, based on studies of individual species. Very few observations on feeding have been done on the species encountered in this study. Until such observations are available, my classification of taxa into feeding modes contains a degree of uncertainty. The following remarks should be viewed with these considerations in mind.

Of the six feeding modes only herbivores were not present in artificial substrates. Herbivore absence is easily explained by the lack of living algae in artificial substrates. The remaining feeding modes were all present at some time during the sampling period in 2, 4, 8, and 12 month substrates. The relative abundance and relative importance of the feeding modes, within each exposure length, fluctuated with substrate type and season, so no clear successional pattern of these ecological groups emerged as the community aged. As was found with taxonomic groupings, the initial stages of colonization by the ecological groups appears to be more influenced by environmental events than by a set successional sequence.

IV. Similarity of Replicates

A community develops when species colonization and extinction, and reproduction and mortality of organisms results in a uni-directional temporal change in the taxonomic composition and/or abundances of individual taxa in the community. This temporal pattern I have previously defined as succession. The comparison of the developments of two communities requires that these temporal patterns be described and contrasted.

I will use MacArthur and Wilson's (1963, 1967) theory of island biogeography to examine succession in artificial substrates. Artificial substrates are not strictly islands, as they are not isolated from similar habitats by inhospitable terrain (Simberloff, 1974). However, apart from this the colonization of open patches in a habitat should be governed by the same factors as is island colonization.

When succession in artificial substrates from Rupert Inlet was examined by describing changes in the major faunal groups, abundant taxa, or ecological groups, no clear temporal pattern emerged in either tailing or control substrates. Due to the variation within each of the these three types of data, these measurements of community development are of limited use when comparing the two substrates used in this study. The lack of an overall pattern can be partly attributed to the effects of seasonality on succession. However, given a constant environment is it reasonable to assume that one temporal pattern would emerge; i.e. that the species composition or ecological groupings at any given time on an island is predictable.

Simberloff and Wilson (1969), in their discussion of MacArthur and Wilson's (1963, 1967) theory of island biogeography, term the initial stages of colonization non-interactive because, they suggest, small population sizes render biotic interactions unimportant to community development. The MacArthur-Wilson model (1963, 1967) assumes that each species from the pool of potential colonists is equally likely to colonize an island. Therefore, the model suggests, that in the initial stages of colonization, the species composition at any time on an island should be a random subset of the potential colonists, and so not predictable.

On average 56% of the taxa found in replicate artificial substrates were common to both replicates. A similar value of 50-60% common species is reported by Osman (1982) for hard artificial substrates. These results indicate that chance immigration plays an important role in benthic community development. It is, however, an over-simplification to assume an equal probability of colonization for all species. Deterministic factors, e.g. superior dispersal or competitive abilities of a species, also influence early colonization. Osman (1982) demonstrates the importance of deterministic processes by showing that species overlap between replicates is 50-60% higher than would be expected if all species had equal probabilities of colonizing an area.

Species colonization of a habitat appears to be a product of both chance and deterministic processes (Schoener, 1982; Osman, 1982). The deterministic species interactions that occur in a habitat will be dictated by the species present. Species composition is partly influenced by chance; hence the type of deterministic processes occurring in a habitat should also be partly a product of chance. Since chance events are probably important in community development, it is unreasonable to expect replicates to follow the same successional path in their species composition. Given this expected variation in taxonomic composition on replicates, it is not surprising that measurements based on changes in individual taxonomic or ecological groupings are frequently too variable to be useful when comparing early community development in similar environments. This intra-replicate variation is of course insignificant when the environments being colonized are very different.

MacArthur and Wilson (1963, 1967) hypothesize that the number of species inhabiting an island at time = t is a stochastic process governed by: the size of the pool of potential colonists, the distance from the source of potential colonists, and the size of an island. Thus, the number of species at time = t on an island is predictable. MacArthur and Wilson's governing factors should be constant between replicates, so the number of species on replicates should be similar.

In contrast to the difference in taxonomic composition between paired replicate artificial substrates, the taxonomic richness and abundance of individuals generally did not differ significantly. Osman (1982) also found that the species number on replicates was similar. It appears that there is little variation in the number of individuals and taxa that colonize replicates. The colonization rate of taxa and perhaps individuals change in a predictable manner in response to MacArthur and Wilson's governing factors (Schoener, 1974; Simberloff, 1976; Osman, 1977, 1982; Henebry and Cairns, 1979). Therefore, a difference in numbers of taxa or individuals between any two habitats of equal age indicates that factors affecting colonization, extinction, reproduction, or mortality in the two habitats are not the same; hence the two communities are developing differently.

V. Community Development

Numerous studies on colonization have demonstrated that the early stages of community development are characterized by an increase in the number of individuals and taxa (Simberloff and Wilson, 1970; Dauer and Simon, 1976b; Arntz and Rumohr, 1982; Schoener, 1982). In temperate latitudes the rise in numbers is rarely described by a smooth colonization curve (number of species plotted against time) (Osman, 1982; Zajac and Whitlatch, 1982a,b; Swarbrick, 1984). Instead, the curve undulates primarily in response to seasonal changes in factors affecting colonization (Arntz and Rumohr, 1982; Osman, 1982; Winiecki and Burrell, 1985). Simberloff and Wilson (1969), Schoener (1974), Arntz and Rumohr (1982), and Dickerson and Robinson (1985) provide evidence to indicate that following the period of increasing species number, two consecutive equilibria occur. First a non-interactive equilibrium is reached. Simberloff and Wilson (1969) suggest that density-dependent biotic interactions then become influential. This causes a decline in species number until a lasting dynamic equilibrium is established, where numbers oscillate around a mean value. The occurrence of a disturbance at any stage in this process may set the community back to a lower successional stage and/or prevent further development (Odum, 1969; Dayton, 1971; Sousa, 1979).

The number of individuals and taxa in artificial substrates did not describe smoothly ascending curves as the communities aged. Rather, in certain seasons the rise in numbers was rapid, while in others little or no increase was detected. In general, abundance and richness increased with community age in artificial substrates initiated from October to June. However, in substrates started in August, numbers remained relatively constant over the winter, but rose again during spring and summer. Recruitment of individuals and taxa into artificial substrates was high from August to October, low from October to April, then rose again from April to August. This seasonal variation in recruitment probably results from corresponding seasonal variations in the rate of reproduction of benthic organisms. Thus, one of the major factors controlling the rate of colonization - the size of the pool of potential colonists - fluctuates seasonally. A rapid fall decrease in this pool and subsequent spring-summer increase appears to be responsible for the winter stasis and spring-summer rise in the number of individuals and taxa in substrates initiated in August.

Apart from the artificial substrates initiated in August, control substrates set out in April were the only other group in which abundance and richness did not always increase with community age. The lack of increase in these controls occurred from two to four months of exposure. This cannot be attributed to a seasonal drop in the size of the pool of potential colonists, because recruitment into two month substrates was high during this period. Further, the number of individuals and taxa in tailing substrates grew with community age from April to August. The lack of increase in these control substrates is difficult to interpret, and at present can only be attributed to the chance occurrence of different larval settlement patterns between the two and four month substrates.

Clearly, the colonization curves for artificial substrates are typified by seasonal, and occasional chance, dips and plateaus. Despite these undulations, the early stages (8-12 months) of tailing and control artificial substrate community development are characterized by an overall increase in numbers of individuals and taxa. The dips and plateaus generally demonstrate temporary decreases in the rate of recruitment. They do not indicate that succession in artificial substrates proceeds without rises in abundance and richness.

The rise in the number of individuals and taxa in artificial substrates showed little evidence of levelling off after 8 to 12 months of community development.

Therefore, an equilibrium species number had not been attained in this time. The time required to reach equilibrium is difficult to predict, and due to the seasonality of colonization will depend on the season in which colonization begins. Nevertheless, soft bottom benthic communities in Rupert Inlet probably require in excess of 12 months to reach equilibrium. This is not unusual. Time to equilibrium exceeding 12 months has been reported for benthic communities by Subrahmayam and Kruczynski (1979), Bonsdorff (1980), Arntz and Rumohr (1982), and Winiecki and Burrell (1985).

Increases in numbers of individuals and taxa reflect the rate at which an equilibrium number is approached by a community. As such, these increases can be used as one measure of the rate of community development; hence they may be used to compare the rate of development of two communities.

I do not mean to imply that increases in individuals and taxa are the only measures of community development, nor should an absence of a numerical increase be interpreted as an absence of community development. Succession may proceed by changes in taxonomic composition or abundances of individual taxa while no change in abundance or richness is evident.

Ordination analysis simultaneously integrates the different successional changes occurring in a community. Principal components analyses of the artificial substrate communities show succession occurring with time. This is evident even in the substrate sets that demonstrated a stasis or decrease in numbers of individuals and taxa with time, i.e. tailing and control substrates started in August and control substrates initiated in April. Succession in these substrates must result through changes in the taxonomic composition and/or abundances of individual taxa.

In substrates initiated in August, a shift in abundances of individual taxa was the major successional event taking place from October to December. Amphipod numbers dropped by at least 50% over this period, while polychaete numbers rose. Thus, despite stability of abundance at the community level, polychaetes were recruiting into 4 month substrates from October to December.

The successional changes that account for the PCA separation of 2 and 4 month substrates initiated in April are not clear. Numerous subtle changes in community structure must be responsible.

VI. Effects of a Tailing Substrate on Colonization and Community Development.

Does a tailing substrate affect the community development process? An effect on development could produce one of four outcomes. If different species are attracted to and survive on the two substrates, then the species composition of the two developing communities will be dissimilar. Alternatively, the same species may colonize the two substrates but in unequal proportions, resulting in a difference in dominant species and species relative abundances. In these two scenarios colonization rate may or may not be affected.

Similar species may recruit to both substrates in approximately equal proportions, but the rate of species colonization minus the rate of extinction (the slope of the colonization curve) may differ. The two communities could eventually converge on the same equilibrium point but at different rates, or the divergent rates could result in dissimilar equilibria.

The PCA of all artificial substrates indicates that tailing and control substrates were colonized by similar taxonomic assemblages. Detailed faunal description further supports this contention. Generally, the two substrates were dominated by the same taxonomic group - polychaetes, and supported the same abundant taxa. Few taxa were restricted to one substrate type. Most of these restricted taxa were encountered only once, hence are probably not important components of the community. Clearly, a tailing substrate did not substantially alter the taxonomic composition or relative abundance structure of the communities developing on artificial substrates. This indicates that a tailing substrate does not exclude or attract select taxa.

In contrast, a tailing substrate did affect the rate of community development. Tailing substrates were consistently colonized by lower numbers of individuals and taxa than their controls. PCA's demonstrate tailing communities developing at slower rates than controls, and diversity was usually lower in tailing substrates.

Polychaetes were the principal taxonomic group that colonized artificial substrates, but also were the group that demonstrated the highest degree of sensitivity to a stable tailing substrate. This indicates that polychaetes would be logical candidates for use in bioassays testing tailing toxicity.

Monitoring of benthic communities subjected to continuous submarine discharge of mine tailings has demonstrated reduction in species number and abundance of individuals in areas of high deposition (Island Copper, 1976-1985; Kathman *et al.*, 1983). Several explanations for this impact have been proposed: high sedimentation rates undoubtedly smother benthos, local obliteration may occur due to shifting tailing piles, and the presence of a tailing substrate may contribute to species and abundance reduction. Monitoring during tailing release cannot determine the relative importance of these effects. It is, therefore, difficult to predict how long impact will continue post discharge. Smothering and substrate instability will probably cease soon after termination of discharge, while perturbation caused by a tailing substrate will continue until the substrate is capped by sedimentation, removed by current scouring, or rendered inert by leaching. The experimental approach used in this study demonstrates that the presence of a tailing substrate can cause a reduction in species number and abundance. Thus, some of the effect of marine tailing discharge on benthic communities will continue post-discharge.

To adequately understand the immediate and long term biological effects of pollutants released to the environment, simply monitoring the receiving system is insufficient. In future, a more widespread use of experimental approaches should be encouraged, to help provide causative explanations for observed biological changes.

The magnitude of the effect of a tailing substrate on colonization rate varied seasonally. This suggests that the proportion of the pool of potential colonists able to survive on tailings changes seasonally. The maximum and minimum effects of a tailing substrate occurred in winter and fall respectively. Winter maxima may result from harsh winter conditions (e.g. low food reserves) weakening potential colonists, thus rendering individuals less able to handle the additional stress of a tailing substrate. Alternatively, the species composition of the pool of potential colonists may change seasonally to produce a winter pool containing a higher proportion of species sensitive to tailings.

A change in the species composition of the pool of potential colonists appears to be responsible for the minimal effect of a tailing substrate in the fall. Amphipods settled in large numbers during the fall, but colonized tailing substrates in higher numbers than contols. This partly obscured the higher colonization rate of polychaetes into control substrates.

Many aspects of communities, for example population size, species composition and growth rates, change seasonally in temperate latitudes. Along with these changes community susceptibility to disturbance probably also fluctuates. Hence, the observed seasonality in the effects of a tailing substrate may not be restricted to tailings, but indicative of a more general pattern. The magnitude of the biological impacts of many other man made and natural disturbances likely also display seasonality. Measurement of the magnitude of impact is not an easy task, and depends on the parameters used to describe the community. However, because many communities change seasonally and annually, to adequately describe the impacts of a disturbance on a community, it is necessary to examine the seasonal and perhaps annual variations in this impact.

Dissimilar colonization rates of tailing and control artificial substrates probably result from a concomitant difference in one or more of the three factors proposed by MacArthur and Wilson (1963, 1967) as determinants of colonization rate. Tailing and control substrates were identical in size and in distance from the source of potential colonists. Therefore, a component of tailings probably reduced the size of the pool of potential colonists. Such an effect could occur if a tailing substrate precluded settlement of some larvae, causing settlement rates to differ between tailing and control substrates. Alternatively, settlement rates may not be affected. Tailings may instead increase species extinction and individual mortality rates, producing a decrease in survival rates.

It is possible that tailings do not reduce settlement or survival, but rather lower growth rates. Some evidence of this is provided by Jones and Ellis (1976), who report an inverse relationship between *Ophelina acuminata* Oersted length and tailing thickness. Lower growth rates would produce an apparent reduction in the colonization rate of tailing artificial substrates, if reduced growth was sufficient to cause a higher proportion of the tailing community to pass through the 0.5 mm screen used in sampling.

What are the long term results of a reduced colonization rate in tailings? Two communities developing at different rates may converge on the same end point, or reach two dissimilar equilibria. Species number equilibrates when the rate of species arrival equals the rate of extinction (MacArthur and Wilson 1963, 1967). Hence, the equilibrium species number on tailings can be forecast if species immigration and extinction rates can be estimated. To achieve this, it is necessary to establish whether tailings are primarily changing species arrival, extinction, or growth rates. Currently, such discrimination cannot be made without further research; however the possible outcomes can be explored.

If tailings increase extinction rates but do not alter species settlement rates, it follows that the equilibrium reached in tailings will contain fewer species than that reached in controls. If the rate of species arrival is lowered by tailings, prediction becomes more complex. Extinction rate is directly related to species number on an island (MacArthur and Wilson 1963, 1967). Reduced settlement will produce a lower species number on tailings, thus lowering the extinction rate. However, tailings may not alter the extinction rate per number of species on an island. For example, the tailing communities will take longer than controls to reach a species number of ten. However, when tailings support ten species the extinction rate will be the same as the rate in control communities when ten species were present. This situation would produce a tailing community with a depressed rate of development, but one which may eventually reach the same equilibrium as the control or natural sediment. The difference in development rate and time to equilibrium between the two communities will be directly related to the difference in rate of species arrival.

Reduced immigration and increased extinction rates are not mutually exclusive, but may co-occur in tailings. This would again result in a lowering of the final equilibrium.

A decrease in growth rates in tailings should not affect species immigration, but could affect extinction rates. For example, lower growth rates may increase the time to reproduction. This may reduce population sizes, which increases the chance of species extinction (MacArthur and Wilson 1963, 1967).

The colonization rates reported here are those occurring at 12-13 m in Rupert Inlet. The majority of tailing deposits in the inlet lie much deeper than this (Rupert Inlet mean depth = 110 m). Rates of benthic infaunal colonization decrease with depth (Grassle, 1977; V.T.N., 1983; Levin and Smith, 1984). This suggests that benthic colonization rates in most of Rupert Inlet will be slower than those observed in this study. In addition, recovery or time to equilibrium may also be slower in the deeper tailing deposits.

To date, the component of Island Copper's tailings responsible for the observed reduction in colonization rate has not been identified. The most likely candidates are the heavy metals contained in tailings, particularly copper and molybdenum whose levels are elevated above concentrations in surrounding natural sediments (Island Copper, 1976-1985). The toxicity of many heavy metals is well documented (Andrew *et al.*, 1976; McIntyre and Mills, 1975; Mackenzie, 1983). For copper in seawater, LC50 values for marine invertebrates range upwards from 50 ugL^{-1} (Spear and Pierce, 1979). Sublethal effects of copper to benthic fauna have also been reported (Broković-Popović and Popović, 1977; Hodson *et al.*, 1979; Phelps *et al.*, 1983, 1985). Island Copper (1982-1984) reports that sediment copper values in Rupert Inlet ranged from 65-1200 ppm from 1982 to 1984. Pedersen (1985) also measured copper concentration in Rupert Inlet, and found values ranging form 210-440 ppm in sediment. Further work is required to assess the toxicity of these levels, as toxic levels of copper in sediment are usually higher than toxic levels in water. The processing reagents added to tailings may also be deleterious to benthos in low concentrations. Unfortunately, the biological effects of many of these additives are largely unknown, even though all have been cleared for use at Island Copper Mine using standard acute bioassays.

Identification of the offending component in tailing is necessary for several reasons. Firstly, this would establish whether the component was unique to Island Copper's tailings or more ubiquitous. If unique the results of this study are applicable only to the Island Copper situation. Probably the component is more cosmopolitan and the findings of this study can be used to understand and predict the impacts of other mines discharging tailings to marine systems. Secondly, isolation of the component would allow a determination of the expected duration of the components biological activity in the system. This would enable prediction of the duration of impact to benthic communities. Lastly, once the component has been identified, research into mitigation and reclamation procedures could be initiated, if the effect is considered significant and undesirable. Practices such as removing the component prior to discharge or capping the tailing substrate once mining ceases, could be explored.

VII. Seasonality

The rate of artificial substrate colonization and community development varied seasonally. Generally, colonization rates for both numbers of individuals and taxa were high in the fall, decreased over the winter, and rose again through the spring and summer. Four month control substrates appear to diverge from this pattern, as abundance and richness display no winter decline. Rather, the number of individuals found in 4 month controls reached minima in the fall and summer, while the number of taxa remained relatively constant throughout the year. This apparent lack of a winter decrease in colonization is probably an artifact of the sampling program. The four month substrates exposed over the winter (October -

February) were lost. Larval settlement rates usually decrease during the winter in temperate latitudes (Osman, 1977; Arntz and Rumohr, 1982; Zajac and Whitlatch, 1982b; Winiecki and Burrell, 1985). In addition, recruitment in 2 month artificial substrates was low over the winter. Therefore, colonization rates of the lost 4 month substrates would probably have been low, and would have displayed the typical winter decrease. The 4 month controls exposed two months later than the lost substrates (December - April) supported high numbers of individuals. An inference of rapid winter recruitment could be drawn from this result. However, the elevated abundance in these controls was primarily caused by a large settlement of sabellids and lumbrinerids. The majority of these individuals were extremely small (approximately 0.5 mm - 1.0 mm), suggesting that they were a product of a spring settlement that occurred just prior to substrate retrieval. Four month control substrates were the only substrates to receive this settlement, so showed a more rapid and pronounced spring increase in abundance than other substrates.

Seasonal fluctuations in colonization of artificial substrates indicate that the rate of soft bottom benthic colonization in Rupert Inlet is low over the winter and increases during spring and summer. The time of maximum rate appears to depend on the age of the community, and the substrate type.

Benthic colonization and community development will be most susceptible to perturbations from tailing discharge during periods of rapid colonization; spring and summer in temperate latitudes. Obliteration or substantial reduction of benthic communities during this time would prevent or significantly change community development, at least until the following spring. Recovery from a similar impact over the winter would begin much faster. Clearly, the timing of tailing discharge dictates the duration and thus the degree of impact. This is an important consideration if sporadic discharge is to be employed or when the date of mine closure is debated.

The observed seasonal fluctuations in the rate of benthic colonization occur primarily in response to seasonal fluctuations in the size and composition of the pool of potential colonists. Size and composition of this pool probably also change annually. The colonization process is not static with time. To adequately describe colonization of a habitat, this variability must be recognized, and an attempt made to examine seasonal and annual patterns.

VIII. Successional Stage of Existing Benthic Communities in Rupert Inlet

Island Copper Mine has been releasing tailings into Rupert Inlet since October 1971. To date tailings have buried the natural substrate and now form the upper layers of the sediment in the inlet (Island Copper, 1976-1985). Existing benthic communities in Rupert Inlet inhabit this tailing substrate and are subjected to the continuing discharge of mine tailings. These conditions appear to impede benthic community development in parts of the inlet (Jones and Ellis, 1976; Island Copper 1976-1985).

The ordination analysis indicates that benthic communities at Island Copper's sampling stations close to the tailing outfall or in the main path of the tailing current, are in very early stages of succession. These stations are located where they experience continued severe disturbance from the tailings discharge; i.e. smothering and extreme substrate instability. This prevents community development beyond initial colonization.

As station distance from the outfall and tailing current increases communities become less similar to those at highly disturbed stations, and more similar to the most developed artificial substrate communities. Benthic community development in Rupert Inlet appears to increase with distance from the outfall, probably in response to a reduction in the frequency and degree of disturbance.

The precise stage of community development at stations removed from the outfall is difficult to assess, because the second ordination axis separates these stations from all artificial substrates. The separation may reflect differences in sampling methods and habitat characteristics such as location, depth, sediment grain size, and organic content. Differences in habitat may cause benthic development in Rupert Inlet to diverge from that in artificial substrates, so distance along axis one no longer directly reflects stage of community development.

CONCLUSIONS

I. Summary

The colonization of tailing and control artificial substrates was characterized by increases in the number of individuals and taxa as the communities aged. Neither substrate type reached an equilibrium species number within the 12 month period of investigation. No one successional sequence of taxa or ecological groups was evident. Instead, successional patterns in artificial substrate communities varied seasonally and with substrate type. Random immigration patterns probably also contributed to the observed variation in succession.

The rate of artificial substrate colonization and community development varied seasonally. Generally, rates were high in the fall, decreased over the winter, and rose again through the spring and summer.

Colonization occurred primarily through larval settlement rather than through adult immigration. In general, polychaetes were the dominant colonists of artificial substrates. Polychaetes were replaced as dominants by amphipods and gastropods in a few tailing substrates exposed over the fall and winter. Pelecypod populations were low overall.

Tailing and control substrates were colonized by similar taxonomic assemblages; therefore tailings were not excluding or attracting select taxa. However, in all seasons and for all exposure lengths observed (1, 2, 4, 8, and 12 months), a tailing substrate retarded community development. The component of tailings responsible for this has not been identified. Currently, it is difficult to predict the long term effects of depressed development in tailings. The tailing community may equilibrate at a lower species number than the control. Alternatively, while development may be slower, the tailing community may eventulally reach the same equilibium as the control.

Macrobenthic communities in Rupert Inlet close to the tailings outfall or in the main path of the turbidity current are in very early stages of succession. Continual disturbance from tailing discharge is probably responsible for this.

The artificial substrate containers designed for this study could be used effectively to examine macrobenthic colonization in many situations. The technique does have time limitations, particularly if used in polluted environments. Over time, sediment from the water column contaminates substrates.

II. Coda

One of the major lessons to be gleaned from the study of ecology, is that the interactions involved in structuring biological systems are extremely complex. Currently, we are only begining to understand these processes and interactions. Despite this, biological systems, whose existence are fundamental to our survival as a species, are continually perturbed by human manipulation and pollution. The ramifications of this perturbation vary widely depending upon the type, intensity, and the receiving environment. Our survival to date is testimony to the fact that the natural environment can accommodate a degree of human perturbation. However, the present rate of disturbance and pollution is, in many instances, too high to be assimilated by biological systems. The result is serious negative repercussions to many members of these system, including ourselves.

If we choose to pursue our current economic polices that dictate ever increasing exploitation of the natural environment, the negative consequences can only escalate unless we seek ways to decrease the impacts of our activities. To do this it is essential that we continue research into the effects of human manipulation and pollution on biological systems. With this research will come an understanding of these systems which will allow assessment of the severity and duration of the impacts from each of our endeavours. In addition, biological knowledge will enable the development of measures to mitigate impacts and to rehabilitate systems once impact ceases. The information provided by research will allow us to decide which and how many of our activities we can sustain while still maintaining the quality of our environment.

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APPENDIX 1

LIST OF TAXONOMIC GROUPINGS USED FOR DATA ANALYSIS.

Numbers indicate taxonomic level used for analysis.

TAXA ANALYSED

Annelida

1.	Oligochaeta
	Polychaeta
	Sedentariate
2.	Ampharetidae
	Amphictenidae
3.	*Pectinaria granulata*
4.	Capitellidae
	Chaetropteridae
5.	*Spiochaetopteris costarum*
6.	Cirratulidae
	Flabelligeridae
7.	*Pherusa plumosa*
8.	Maldanidae
	Magelonidae
9.	*Magelona* sp.
10.	Opheliidae
11.	Orbiniidae
12.	Sabellidae
	Spionidae
13.	*Polydora* sp.
14.	*Prionospio cirrifera*
15.	*Prionospio steenstrupi*
16.	Terebellidae
	Trichobranchidae
17.	*Terebellides stroemi*
	Errantiate
	Dorvilleidae
18.	*Schistomeringos longicornis*
	Glyceridae
19.	*Glycera capitata*
	Goniadidae
20.	*Glycinde* sp.
21.	*Goniada maculata*
	Lumbrineridae
22.	*Lumbrineris* sp.
	Nephtyidae
23.	*Nephtys* sp.
	Nereidae
24.	*Neris* sp.
	Onuphidae
25.	*Nothria conchylega*
	Phyllodocidae

26. *Eteone longa*
27. *Eulalia* sp.
28. *Phyllodoce* sp.
29. Polynoidae
Sigalionidae
30. *Pholoides aspera*
Syllidae
31. *Sphaerosyllis brandhorsti*

Arthropoda

Crustacea
Amphipoda
Ampeliscidae
32. *Ampelisca pugetica*
33. *Byblis* sp.
Dexaminidae
34. *Dexamonica reductans*
Isaeidae
35. *Corophium* sp.
36. *Photis* sp.
37. *Protomedia articulata*
Ischyroceridae
38. *Jassa* sp.
Oedicerotidae
39. *Monoculodes* sp.
40. *Synchelidium shoemakeri*
41. *Westwoodilla caecula*
42. Podoceridae
Podocerid sp.

43. Ostracoda

44. Cumacea

Mollusca

Gastropoda
Buccinidae
45. *Amphissa columbiana*
Columbellidae
46. *Mitrella* sp.
47. *Nitidella* sp.
Nassariidae
48. *Nassarius mendicus*
Rissoidae
49. *Alvania compacta*

50. Opisthobranchia

51. Pelecypoda

Cnidaria

52. Anthozoa

53. Nemertinea

54 Nematoda

Echinodermata

55. Holothuroidea

APPENDIX 2

METHODS OF HEAVY METAL ANALYSIS USES BY ISLAND COPPER-UTAH MINES.

TOTAL METALS IN SEDIMENTS
ATOMIC ABSORPTION METHODS

Definition:

The concentration of metals determined in a homogenous sediment sample following digestion.

Applications:

Marine and freshwater sediments

Sampling and Storage:

Place the sediment on an acid-washed watchglass and dry in the oven at a temperature below 60°C. When dry, crush in a clean mortar and pestle and seive through 100 mesh screen. Store the fraction that is less than 100 mesh in a clean sample bag until analysis can be done.

Apparatus:

Wash all glassware with aqua regia. Rinse with deionized water.

1. 250 ml Teflon beakers and cover.
2. 100 ml volumetric flasks
3. Whatman #40 filter papers and funnels
4. volumetric flasks and pipets for dilutions where necessary.

Reagents:

1. concentrated nitric acid, Aristar grade
2. concentrated hydrochloric acid, Aristar grade
3. concentrated perchloric acid, Aristar grade
4. concentrated hydrofluoric acid, Aristar grade
5. 18% Aluminum Chloride Solution ($AlCl_3$)
   Dissolve 36 g. $AlCl_3.6H_2O$ in 200 ml deionized water.

Procedure:

1. Transfer exactly 2 g. sediment sample to a 250 ml beaker. Run blanks on reagents only. Run standards.

2. Add 10 ml conc. HNO_3 and 5 ml conc. HCl. Cover and boil until red fumes are driven off.

3. Cool and add 7 ml conc. $HClO_4$. Remove covers and heat on moderate heat until the volume is reduced to about 10 ml.
4. Add approx. 4 ml conc. HF and take to dryness. Complete digestion of the sample is indicated by a light coloured residue.
5. Cool, add 5 ml conc. HCl, and rinse down sides of beaker with deionized water, and heat to dissolve residue.
6. Transfer the hot sample quantitatively through a #40 filter paper to a 100 ml volumetric flask. Add 5 ml of $AlCl_3$ solution. Rinse the beaker and the filter paper thoroughly with hot deionized water and make up the volume to 100 ml.
7. Run on the A.A. for Cu, Ni, Fe, Mn, Co, Cr, Pb, Mo, Cd, Zn, using dilutions where necessary.

NOTE:

When running molybdenum, it is necessary to add aluminum chloride to samples and standards to ensure that aluminum enhancement of the Mo peak will be the same in both.

Calculations:

1. Prepare a calibration curve from readings obtained for the standard solutions.
2. Compare readings for the samples with the standard curve, and correct for any blank reading.
3. ug/g metal in sediment = $\frac{\text{ug/ml metal in sample} \times 100\text{ ml}}{\text{weight sediment (2 g.)}}$

Reporting of Results:

1. Results are recorded on the computer sheets (code 57)

Reference:

DIGESTION:	Dept. of Geology, University of British Columbia Procedure for Soil Geochemical Atomic Absorption.
ANALYSIS:	Perkin Elmer, Analytical Methods for Atomic Absorption Spectrophotometry.

APPENDIX 3

MEDIAN GRAIN SIZE AND DEGREE OF SORTING OF SEDIMENTS IN ARTIFICIAL SUBSTRATE CONTAINERS.

See table 1 for artificial substrate codes.

	MEDIAN GRAIN SIZE DIAMETER (mm)			SORTING COEFFICIENT	
Artificial Substrate	Pre-Exposure	Post-Exposure	Change from Pre- to Post-Exposure	Pre-Exposure	Post-Exposure
T2A-O(a)	0.028	0.042	+0.014	2.21	2.04
T2A-O(b)	0.024	0.035	+0.011	2.49	2.20
T2D-F(a)	0.083	0.078	-0.005	1.91	2.10
T2D-F(b)	0.072	0.076	+0.004	2.20	2.03
T2Ap-J(a)	0.037	0.038	+0.001	2.32	2.62
T2Ap-J(b)	0.056	0.047	-0.009	1.83	2.04
T2J-A(a)	0.034	0.032	-0.002	2.68	2.59
T2J-A(b)	0.045	0.042	-0.003	2.34	2.33
T4A-D(a)	0.026	0.038	+0.012	2.57	2.09
T4A-D(b)	0.027	0.033	+0.006	2.19	1.18
T4D-Ap(a)	0.084	0.086	+0.002	1.18	1.97
T4D-Ap(b)	0.077	0.078	+0.001	2.24	2.16
T4Ap-A(a)	0.055	0.055	0.000	2.12	2.15
T4Ap-A(b)	0.050	0.056	+0.006	2.13	2.05
T8A-Ap(a)	0.027	0.033	+0.006	2.22	2.17
T8A-Ap(b)	0.024	0.033	+0.009	2.39	1.97
T12A-A(b)	0.032	0.034	+0.002	2.30	2.48
Mean	0.046		+0.003		
Std. dev.	0.022		+0.006		

	MEDIAN GRAIN SIZE DIAMETER (mm)			SORTING COEFFICIENT	
Artificial Substrate	Pre-Exposure	Post-Exposure	Change from Pre- to Post-Exposure	Pre-Exposure	Post-Exposure
C2A-O(a)	0.097	0.110	+0.013	1.42	1.38
C2A-O(b)	0.097	0.110	+0.013	1.42	1.39
C2D-F(a)	0.097	0.083	-0.014	1.42	1.45
C2D-F(b)	0.097	0.082	-0.015	1.42	1.52
C2Ap-J(a)	0.097	0.130	+0.033	1.42	1.43
C2Ap-J(b)	0.097	0.120	+0.023	1.42	1.41
C2J-A(a)	0.097	0.076	-0.021	1.42	1.56
C2J-A(b)	0.097	0.075	-0.022	1.42	1.48
C4A-D(a)	0.097	0.160	+0.063	1.42	1.46
C4D-Ap(a)	0.097	0.086	-0.011	1.42	1.50
C4D-Ap(b)	0.097	0.078	-0.019	1.42	1.38
C4Ap-A(a)	0.097	0.125	+0.028	1.42	1.46
C4Ap-A(b)	0.097	0.120	+0.023	1.42	1.43
C8A-Ap(b)	0.097	0.120	+0.023	1.42	1.37
Mean			+0.008		
Std. dev.			+0.026		

APPENDIX 4

PH OF MINE TAILINGS AND MARBLE SAND IN SEA WATER.

	Time (hr)		
	0	12	48
Seawater	8.2	8.1	8.2
Tailings + seawater	8.0	8.0	8.0
Marble sand + seawater	7.9	7.9	8.1

APPENDIX 5

SEDIMENT DEPTH IN SEDIMENT TRAP AND ARTIFICIAL SUBSTRATE CONTAINERS.

See table 1 for artificial substrate codes.
(-):missing datum.

Artificial Substrate Containers	Sediment Depth in Trap (cm)	Sediment Depth in Container (cm) Post Exposure (10 cm pre-exposure)
T2Ap-J(a)	-	9.0
T2Ap-J(b)	-	9.0
C2Ap-J(a)	-	8.5
T2J-A(a)	-	9.5
T2J-A(b)	-	9.0
C2J-A(a)	-	9.0
C2J-A(b)	-	8.5
T4A-D(a)	0.5	-
T4A-D(b)	0.1	-
C4A-D(a)	0.2	-
T4D-Ap(a)	0.8	-
T4D-Ap(b)	0.6	-
C4D-Ap(a)	0.6	-
T4F-J(a)	0.5	8.0
T4F-J(b)	3.0	8.0
C4F-J(a)	0.3	9.5
C4F-J(b)	0.5	7.0
T4Ap-A(a)	1.2	9.5
T4Ap-A(b)	1.2	8.0
C4Ap-A(a)	1.0	8.0
C4Ap-A(b)	1.1	6.0
T8A-Ap(a)	1.1	-
T8A-Ap(b)	0.8	-
C8A-Ap(b)	1.1	-
T8O-J(a)	-	7.5
C8O-J(a)	0.7	7.5
T12A-A(b)	3.0	7.0

APPENDIX 6

RAW DATA: TAXONOMIC LISTS AND ABUNDANCES OF INDIVIDUAL TAXA IN EACH ARTIFICIAL SUBSTRATE CONTAINER.

See table 1 for artificial substrate codes.

Abbreviations for species authority (authors of species names):

Barnard	BA
Baird	BI
Bate	BT
Berkeley	B
Berkeley and Berkeley	BB
Carpenter	C
Ciaparede	CL
Conrad	CO
Dall	D
Ehlers	E
Fabricius	F
Gould	G
Hartman	H
Hartman and Schroder	HS
Johnson	J
Linnaeus	L
Malmgren	M
Mills	MI
Moore	MO
Muller	MU
Oersted	O
Pettibone	P
Quatrefages	Q
Sars	S
Stimpson	ST
Verrill	V
Wiren	W

	ARTIFICIAL SUBSTRATE									
	1J1-A				2A-O				2O-D	
TAXA	T	T	C	C	T	T	C	C	T	T
Oligochatea	0	0	0	0	0	0	0	0	0	0
Ampharetidae	1	0	0	1	1	0	1	2	0	0
Ampharete finmarchica (S)	0	0	0	0	0	0	0	0	0	0
Pectinaria granulata (L)	0	0	3	0	0	1	2	2	0	1
Capitellidae	0	0	0	0	0	0	0	0	0	0
Spoichaetopterus costarum (CL)	0	0	0	0	0	0	1	0	0	0
Cirratulidae	0	0	0	0	0	1	0	0	0	1
Chaetozone setosa M	0	0	0	0	0	0	0	0	0	0
Tharyx multifilis MO	0	0	0	0	0	0	0	0	0	0
Pherusa plumosa (MU)	0	0	0	0	0	0	0	0	0	0
Maldanidae	0	0	0	0	0	0	0	0	0	0
Euchymene cf. zonalis (V)	0	0	0	0	0	0	0	0	0	0
Praxillella gracilis (S)	0	0	0	0	0	0	0	0	0	0
Magelona sp.	0	0	0	0	0	0	0	0	0	0
Opheliidae	0	0	0	1	0	0	0	1	0	0
Armandia brevis (MO)	0	0	3	9	6	2	18	11	0	0
Ophelina acuminata O	0	0	0	2	0	0	0	0	0	0
Orbiniidae	0	0	1	1	2	0	1	0	0	0
Leitoscoloplos pugettensis (P)	0	1	0	0	0	0	0	0	0	0
Sabellidae	0	0	0	0	1	0	0	0	1	0
Chone duneri M	0	0	0	0	0	0	0	0	0	0
Echone incolor H	0	0	0	0	0	0	1	0	0	0
Pseudopotamilla sp.	0	0	0	0	0	0	0	0	0	0
Polydora sp.	0	0	0	1	0	2	1	0	0	0
Polydora bracycephala H	0	0	0	0	0	0	0	0	0	0
Polydora cardalia B	1	1	22	24	2	3	4	1	0	0
Prionospio cirrifera W	0	0	3	6	2	4	0	0	0	0
Prionospio steenstrupi M	0	3	1	0	0	1	2	8	0	0
Terebellidae	0	0	4	8	2	1	2	3	0	0
Pista cristata (MU)	0	1	1	0	0	0	1	1	0	0
Thelepus setosus (Q)	0	0	0	0	0	0	0	1	0	0
Terebillides stroemi S	0	0	0	0	0	0	0	0	0	0
Shistomeringos longicornis (E)	0	0	0	0	0	0	0	0	0	0
Glycera capitata O	0	0	0	0	0	0	0	0	0	0
Goniadidae	0	0	0	0	0	0	0	0	0	0
Glycinde sp.	0	0	0	0	0	1	1	0	0	0
Glycinde picta B	0	0	0	0	0	1	2	4	0	0
Goniada maculata O	0	0	0	0	0	0	0	0	0	0
Lumbrineris sp.	0	2	0	0	4	0	5	1	1	0
Lumbrineris cruzensis H	0	1	2	2	0	0	0	0	0	0
Lumbrineris luti BB	0	2	3	3	2	2	2	5	1	0
Nephtys sp.	0	0	0	0	0	0	0	0	0	0
Neris sp.	0	0	0	0	0	0	0	0	0	0
Nothria conchylega(S)	0	0	0	0	0	0	0	0	0	0
Eteone longa (F)	0	0	0	0	0	0	1	0	0	0
Eulalia sp.	0	0	0	0	0	0	1	0	0	0
Phyllodoce sp.	1	1	0	2	1	0	0	1	0	0
Polynoidae	0	0	0	0	0	0	0	1	0	0
Harmothoe imbricata (L)	0	0	0	0	0	0	0	1	0	0
Pholoides aspera (J)	0	0	0	0	0	0	0	0	0	0
Sphaerosyllis brandhorsti HS	0	0	1	2	0	0	2	0	0	0
Ampelisca pugetica ST	0	0	0	1	0	0	0	0	0	0
Byblis sp.	0	0	0	0	0	0	0	0	0	0
Protomedia articulata BA	7	3	10	14	14	37	10	23	2	6
Photis sp.	0	0	2	2	4	0	2	0	0	0
Corophium sp.	0	0	1	0	0	0	0	0	0	0
Jassa sp.	0	0	0	0	0	0	0	0	0	0
Podoceridae	0	1	1	0	0	0	0	0	0	0
Dexamonica reductans BA	0	0	1	0	0	0	0	0	0	0
Monoculodes sp.	0	0	1	0	0	1	1	0	0	0
Synchelidium shoemakeri MI	7	1	13	5	0	0	3	2	0	0
Westwoodilla caecula BT	8	10	8	15	0	1	6	2	0	0
Ostracoda	1	0	0	2	3	2	2	2	0	0
Cumacea	2	1	1	4	0	0	0	0	0	0
Alvania compacta C	1	2	3	15	38	3	47	7	6	3
Amphissa columbiana D	0	0	0	0	0	0	0	0	0	0
Mitrella sp.	0	0	0	0	0	0	0	0	0	0
Nitidella gouldi (C)	0	0	0	0	0	0	0	0	0	0
Nassarius mendicus (G)	0	0	0	0	0	0	0	0	0	0
Opithobranchia	0	1	0	0	0	0	0	0	0	0
Pelecypoda -juveniles	0	0	0	0	0	3	0	1	0	0
Clinocardium cf. fucanum (D)	0	0	0	0	0	0	0	1	0	0
Cardiomya californica (D)	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata (C)	0	0	0	0	0	0	0	0	0	0
Protothaca staminea (CO)	0	0	0	0	0	0	0	0	0	0
Psephidia lordi (BI)	0	0	1	1	0	0	0	0	0	0
Anthozoa	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	2	2	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0

TAXA	ARTIFICIAL SUBSTRATE									
	2D-F				2F-Ap				2Ap-J	
	T	T	C	C	T	T	C	C	T	T
Oligochatea	0	0	0	0	0	0	0	0	0	0
Ampharetidae	0	0	0	0	0	0	0	0	0	0
Ampharete finmarchica (S)	0	0	0	0	0	0	0	0	0	0
Pectinaria granulata (L)	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0
Spoichaetopterus costarum (CL)	0	0	0	0	0	0	0	0	0	0
Cirratulidae	0	0	0	0	0	0	0	0	0	0
Chaetozone setosa M	0	0	0	0	0	0	0	0	0	0
Tharyx multifilis MO	0	0	0	0	0	0	0	0	0	0
Pherusa plumosa (MU)	0	0	0	0	0	0	0	0	0	0
Maldanidae	2	0	0	0	0	0	0	0	1	0
Euchymene cf. zonalis (V)	0	0	0	0	0	0	0	0	0	0
Praxillella gracilis (S)	0	0	0	0	0	0	0	0	0	0
Magelona sp.	0	0	0	0	0	0	0	0	0	0
Opheliidae	0	0	0	0	0	0	0	0	0	0
Armandia brevis (MO)	0	0	0	0	0	1	0	0	0	0
Ophelina acuminata O	0	0	0	0	0	0	0	0	0	0
Orbiniidae	0	0	0	0	0	0	0	0	0	0
Leitoscoloplos pugettensis (P)	0	0	0	0	0	0	0	0	0	0
Sabellidae	1	0	0	0	0	0	0	1	0	0
Chone duneri M	0	0	0	0	0	0	0	0	0	1
Echone incolor H	0	0	0	0	0	0	0	0	0	0
Pseudopotamilla sp.	0	0	0	0	0	0	0	0	0	0
Polydora sp.	0	0	0	0	0	0	0	0	0	0
Polydora bracycephala H	0	0	0	0	0	0	0	0	0	0
Polydora cardalia B	0	0	0	0	0	0	0	0	1	4
Prionospio cirrifera W	0	0	1	1	0	0	0	0	0	0
Prionospio steenstrupi M	0	0	0	0	0	0	0	0	2	1
Terebellidae	0	0	0	0	0	0	0	0	0	0
Pista cristata (MU)	0	0	1	0	0	0	0	0	0	0
Thelepus setosus (Q)	0	0	0	0	0	0	0	0	0	0
Terebillides stroemi S	0	0	0	0	0	0	0	0	0	0
Shistomeringos longicornis (E)	0	0	0	0	0	0	0	0	0	0
Glycera capitata O	0	0	0	0	0	0	0	0	0	1
Goniadidae	0	0	0	0	0	0	0	0	0	0
Glycinde sp.	0	0	0	0	0	0	0	0	1	0
Glycinde picta B	0	0	0	0	0	0	1	0	0	0
Goniada maculata O	0	0	0	2	0	0	1	0	0	0
Lumbrineris sp.	0	0	0	0	0	1	3	2	2	4
Lumbrineris cruzensis H	0	0	1	0	0	0	0	1	0	0
Lumbrineris luti BB	0	0	1	3	3	3	8	14	9	4
Nephtys sp.	0	0	0	0	0	0	0	0	0	0
Neris sp.	0	0	0	0	0	0	0	0	0	0
Nothria conchylega (S)	0	0	0	0	0	0	0	0	0	0
Eteone longa (F)	0	0	0	0	0	0	0	0	0	0
Eulalia sp.	0	0	0	0	0	0	0	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0	0	0
Polynoidae	0	0	0	0	0	0	0	0	0	0
Harmothoe imbricata (L)	0	0	1	0	0	0	0	0	0	0
Pholoides aspera (J)	0	0	0	0	0	0	0	1	0	0
Sphaerosyllis brandhorsti HS	0	0	0	0	0	0	0	0	0	0
Ampelisca pugetica ST	0	0	0	0	0	0	3	3	1	1
Byblis sp.	0	0	0	0	0	0	0	1	0	0
Protomedia articulata BA	0	0	0	0	1	0	0	1	1	0
Photis sp.	0	0	0	0	0	0	0	0	0	0
Corophium sp.	0	0	0	0	0	0	0	0	0	1
Jassa sp.	0	0	0	0	0	0	0	0	0	0
Podoceridae	0	0	0	0	0	0	0	0	0	0
Dexamonica reductans BA	0	0	0	0	0	0	0	0	0	1
Monoculodes sp.	0	0	0	0	0	0	0	0	0	0
Synchelidium shoemakeri MI	0	0	0	0	0	0	0	1	0	0
Westwoodilla caecula BT	0	0	0	0	0	0	1	0	0	4
Ostracoda	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	0	1	0	0	4	2	3
Alvania compacta C	0	0	0	2	2	2	0	0	4	0
Amphissa columbiana D	0	0	0	0	0	0	0	0	0	0
Mitrella sp.	0	0	0	0	0	0	0	0	0	0
Nitidella gouldi (C)	0	0	0	0	0	0	0	0	1	2
Nassarius mendicus (G)	0	0	0	0	0	0	0	0	0	0
Opithobranchia	0	0	0	0	0	0	0	0	0	0
Pelecypoda -juveniles	0	0	3	1	0	1	2	11	2	1
Clinocardium cf. fucanum (D)	0	0	0	0	0	0	0	0	0	0
Cardiomya californica (D)	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata (C)	0	0	0	1	0	0	0	0	6	0
Protothaca staminea (CO)	0	0	0	0	0	0	0	0	0	0
Psephidia lordi (BI)	0	0	0	0	0	0	0	0	3	3
Anthozoa	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0

TAXA	ARTIFICIAL SUBSTRATES									
	2Ap-J		2J-A				4A-D			4D-Ap
	C	C	T	T	C	C	T	T	C	T
Oligochatea	0	0	0	0	0	0	0	0	0	0
Ampharetidae	0	0	0	0	0	0	0	1	0	0
Ampharete finmarchica (S)	0	0	0	0	0	0	0	1	0	0
Pectinaria granulata (L)	0	0	1	1	3	6	0	2	1	0
Capitellidae	48	7	0	2	0	2	1	1	0	0
Spoichaetopterus costarum (CL)	1	0	0	0	0	0	0	0	0	0
Cirratulidae	0	0	0	0	0	0	0	0	0	0
Chaetozone setosa M	0	0	0	0	0	0	1	2	1	0
Tharyx multifilis MO	0	0	0	0	0	0	0	2	0	0
Pherusa plumosa (MU)	1	0	0	0	0	0	0	0	0	0
Maldanidae	0	0	0	0	0	0	0	2	0	0
Euchymene cf. zonalis (V)	0	0	0	0	0	0	0	0	0	0
Praxillella gracilis (S)	0	0	0	0	0	0	0	1	0	0
Magelona sp.	0	0	0	0	1	0	0	0	0	0
Opheliidae	0	0	0	0	0	0	0	0	0	0
Armandia brevis (MO)	1	0	0	0	9	9	2	0	16	0
Ophelina acuminata O	1	0	0	0	0	0	0	0	1	0
Orbiniidae	2	2	1	0	1	2	0	1	2	0
Leitoscoloplos pugettensis (P)	0	0	0	0	0	1	1	0	0	0
Sabellidae	0	1	0	0	3	1	0	0	1	0
Chone duneri M	1	0	0	0	0	1	0	0	0	0
Echone incolor H	0	0	0	0	0	0	0	0	0	0
Pseudopotamilla sp.	0	0	0	0	0	0	0	0	0	0
Polydora sp.	1	0	0	0	0	0	0	0	0	0
Polydora bracycephala H	1	1	0	0	0	0	0	0	0	0
Polydora cardalia B	12	3	7	2	51	36	0	4	1	0
Prionospio cirrifera W	1	1	1	2	7	2	13	13	4	0
Prionospio steenstrupi M	3	1	0	0	0	0	1	0	0	0
Terebellidae	0	1	2	4	29	18	1	0	4	0
Pista cristata (MU)	0	0	0	0	0	1	0	1	4	0
Thelepus setosus (Q)	0	0	0	0	0	0	0	1	1	0
Terebillides stroemi S	0	0	0	0	0	0	1	0	0	0
Shistomeringos longicornis (E)	0	0	0	0	0	0	0	0	1	0
Glycera capitata O	2	0	0	0	0	0	0	0	0	0
Goniadidae	0	0	0	0	1	0	0	0	0	0
Glycinde sp.	0	0	0	0	0	1	0	0	0	0
Glycinde picta B	2	0	0	0	1	1	0	1	6	0
Goniada maculata O	0	0	0	0	0	0	0	1	3	0
Lumbrineris sp.	6	4	9	2	1	6	2	8	7	0
Lumbrineris cruzensis H	1	0	1	0	1	1	0	0	2	0
Lumbrineris luti BB	14	0	6	6	8	5	13	24	5	0
Nephtys sp.	0	0	0	0	1	0	0	0	2	0
Neris sp.	0	0	0	0	0	0	0	0	0	0
Nothria conchylega (S)	0	0	0	0	0	0	0	0	0	0
Eteone longa (F)	0	0	0	0	0	0	0	0	0	0
Eulalia sp.	0	0	0	0	0	0	0	0	0	0
Phyllodoce sp.	1	0	0	0	0	0	0	0	0	0
Polynoidae	0	0	0	0	0	1	0	0	0	0
Harmothoe imbricata (L)	0	1	0	0	0	0	0	0	1	0
Pholoides aspera (J)	0	0	0	0	0	0	0	0	0	0
Sphaerosyllis brandhorsti HS	0	0	0	2	2	0	0	0	0	0
Ampelisca pugetica ST	2	2	0	0	2	0	0	0	0	0
Byblis sp.	0	0	1	0	1	1	0	1	2	0
Protomedia articulata BA	0	0	0	1	0	0	13	12	3	0
Photis sp.	0	0	0	0	0	0	0	0	0	0
Corophium sp.	0	0	0	0	0	0	0	0	0	0
Jassa sp.	0	0	0	0	5	1	0	0	0	0
Podoceridae	0	0	0	1	0	0	0	0	0	0
Dexamonica reductans BA	1	0	0	0	0	0	0	0	0	0
Monoculodes sp.	0	0	1	1	0	0	0	1	0	0
Synchelidium shoemakeri MI	0	0	0	0	0	1	0	0	0	0
Westwoodilla caecula BT	0	0	5	5	4	6	0	1	0	0
Ostracoda	0	0	2	1	1	0	0	1	0	0
Cumacea	0	1	0	0	0	0	0	0	0	0
Alvania compacta C	4	0	0	1	0	1	7	3	20	2
Amphissa columbiana D	0	0	0	0	0	0	0	0	0	0
Mitrella sp.	0	0	3	1	0	1	0	0	0	0
Nitidella gouldi (C)	1	1	0	0	0	0	0	0	0	0
Nassarius mendicus (G)	0	0	0	0	0	0	0	0	0	0
Opithobranchia	0	0	0	0	0	0	0	0	0	0
Pelecypoda -juveniles	4	1	0	0	1	2	3	3	2	1
Clinocardium cf. fucanum (D)	0	0	0	0	0	0	0	0	0	0
Cardiomya californica (D)	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata (C)	2	0	0	0	0	0	0	1	0	0
Protothaca staminea (CO)	0	0	0	0	0	0	0	1	0	0
Psephidia lordi (BI)	0	0	1	0	1	3	0	1	3	0
Anthozoa	0	0	0	0	0	1	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0

ARTIFICIAL SUBSTRATE

TAXA	4D-Ap			4F-J				4Ap-A		
	T	C	C	T	T	C	C	T	T	C
Oligochatea	0	0	0	0	1	0	0	0	0	0
Ampharetidae	0	0	0	0	0	0	0	3	0	0
Ampharete finmarchica (S)	0	0	0	0	0	0	0	0	0	0
Pectinaria granulata (L)	0	1	0	0	0	0	0	1	0	0
Capitellidae	0	0	0	0	0	2	0	3	0	8
Spoichaetopterus costarum (CL)	0	0	0	1	0	0	0	0	0	0
Cirratulidae	0	0	0	0	0	0	0	0	0	0
Chaetozone setosa M	0	0	0	0	0	0	0	0	0	0
Tharyx multifilis MO	0	0	0	0	0	0	0	0	0	0
Pherusa plumosa (MU)	0	0	0	0	0	0	0	0	0	0
Maldanidae	0	0	0	0	0	0	0	1	1	2
Euchymene cf. zonalis (V)	0	1	0	0	0	0	0	0	0	0
Praxillella gracilis (S)	0	0	0	0	0	1	0	0	0	0
Magelona sp.	0	0	0	0	0	0	0	0	0	0
Opheliidae	0	0	0	0	0	0	0	0	0	0
Armandia brevis (MO)	0	0	0	0	0	0	0	4	0	0
Ophelina acuminata O	0	0	0	0	0	0	0	0	0	1
Orbiniidae	0	0	0	0	0	1	0	7	2	3
Leitoscoloplos pugettensis (P)	0	0	0	0	0	0	0	0	0	0
Sabellidae	0	31	65	0	0	5	7	2	0	1
Chone duneri M	0	0	0	0	0	1	1	0	0	1
Echone incolor H	0	0	0	0	0	0	0	0	0	0
Pseudopotamilla sp.	0	0	0	0	0	1	0	0	0	0
Polydora sp.	0	0	0	0	0	1	0	0	1	0
Polydora bracycephala H	0	0	0	1	0	0	0	0	0	1
Polydora cardalia B	0	0	0	0	0	1	2	5	0	11
Prionospio cirrifera W	0	0	1	0	0	6	4	1	0	0
Prionospio steenstrupi M	0	0	0	0	0	3	2	0	0	2
Terebellidae	0	1	3	2	0	0	1	1	1	0
Pista cristata (MU)	0	0	0	0	0	0	0	14	0	2
Thelepus setosus (Q)	0	0	0	0	0	0	0	0	0	0
Terebillides stroemi S	0	0	0	0	0	0	0	0	0	0
Shistomeringos longicornis (E)	0	0	0	0	0	0	0	0	0	0
Glycera capitata O	0	0	0	0	0	1	0	3	1	2
Goniadidae	0	0	0	0	0	0	0	0	0	0
Glycinde sp.	0	0	0	0	0	0	0	0	0	0
Glycinde picta B	0	1	1	0	0	4	0	2	0	0
Goniada maculata O	0	0	0	0	0	0	0	0	0	0
Lumbrineris sp.	2	5	10	4	4	28	25	14	9	11
Lumbrineris cruzensis H	0	0	0	0	0	1	0	0	0	2
Lumbrineris luti BB	2	40	36	12	13	37	27	24	14	21
Nephtys sp.	0	0	0	0	0	0	0	0	0	0
Neris sp.	0	0	0	0	0	0	0	0	0	0
Nothria conchylega (S)	0	0	0	0	0	0	0	0	0	1
Eteone longa (F)	0	0	0	0	0	0	0	0	0	0
Eulalia sp.	0	0	0	0	0	0	0	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0	0	0
Polynoidae	0	0	0	1	1	0	0	0	0	0
Harmothoe imbricata (L)	0	0	0	0	0	1	0	0	0	0
Pholoides aspera (J)	0	0	0	0	0	0	0	0	0	0
Sphaerosyllis brandhorsti HS	0	1	0	0	0	0	0	0	0	0
Ampelisca pugetica ST	0	2	3	0	0	0	0	0	0	0
Byblis sp.	0	1	0	0	0	0	1	1	0	0
Protomedia articulata BA	0	0	0	1	0	1	0	0	0	0
Photis sp.	0	0	0	0	0	0	0	0	1	0
Corophium sp.	0	0	0	0	0	0	0	0	0	0
Jassa sp.	0	0	0	0	0	0	0	0	0	0
Podoceridae	0	0	0	0	0	0	0	0	0	0
Dexamonica reductans BA	0	0	0	0	0	0	0	0	0	0
Monoculodes sp.	0	0	0	1	0	0	0	0	0	0
Synchelidium shoemakeri MI	0	3	0	0	0	0	0	0	0	0
Westwoodilla caecula BT	0	1	0	1	0	1	1	0	0	1
Ostracoda	0	0	0	0	0	0	0	1	0	0
Cumacea	0	6	7	0	0	0	0	1	0	0
Alvania compacta C	8	1	5	4	2	2	0	0	1	1
Amphissa columbiana D	0	0	0	0	0	0	0	0	0	0
Mitrella sp.	0	0	0	0	0	0	0	0	1	1
Nitidella gouldi (C)	0	0	0	3	1	2	2	0	0	0
Nassarius mendicus (G)	0	1	0	1	0	0	0	0	0	0
Opithobranchia	0	0	0	0	0	0	0	0	0	0
Pelecypoda -juveniles	0	8	9	0	0	0	4	0	0	2
Clinocardium cf. fucanum (D)	0	0	0	0	0	0	0	1	0	0
Cardiomya californica (D)	0	0	0	0	0	0	0	1	0	0
Axinopsida serricata (C)	0	0	0	0	2	1	1	6	0	0
Protothaca staminea (CO)	0	0	0	0	0	0	0	0	0	0
Psephidia lordi (BI)	0	0	0	2	0	6	1	1	0	0
Anthozoa	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	1	0	0	0	0	0
Holothuroidea	0	0	0	0	0	1	0	0	0	0

	ARTIFICIAL SUBSTRATE						
	4Ap-A	8A-Ap			8O-J		12A-A
TAXA	C	T	T	C	T	C	T
Oligochatea	0	0	0	0	0	0	0
Ampharetidae	0	0	0	0	0	4	6
Ampharete finmarchica (S)	0	0	0	0	0	0	0
Pectinaria granulata (L)	2	3	0	2	0	0	3
Capitellidae	1	1	3	6	0	4	36
Spoichaetopterus costarum (CL)	0	0	0	1	0	0	0
Cirratulidae	0	1	0	0	0	0	0
Chaetozone setosa M	0	3	1	1	0	0	5
Tharyx multifilis MO	0	0	0	0	0	0	0
Pherusa plumosa (MU)	0	0	0	0	0	0	0
Maldanidae	0	0	0	1	0	14	0
Euchymene cf. zonalis (V)	0	0	0	0	0	1	0
Praxillella gracilis (S)	0	0	0	0	0	0	1
Magelona sp.	0	0	0	0	0	0	0
Opheliidae	0	0	0	0	0	2	0
Armandia brevis (MO)	0	0	0	2	0	0	0
Ophelina acuminata O	1	0	0	1	0	3	1
Orbiniidae	2	1	0	0	0	0	4
Leitoscoloplos pugettensis (P)	0	0	0	1	0	1	1
Sabellidae	1	5	3	30	0	12	22
Chone duneri M	1	0	0	0	0	7	4
Echone incolor H	0	0	0	0	0	0	1
Pseudopotamilla sp.	0	0	0	0	0	0	0
Polydora sp.	0	0	0	0	0	0	0
Polydora bracycephala H	5	0	0	0	1	18	1
Polydora cardalia B	6	2	0	0	1	3	10
Prionospio cirrifera W	2	1	10	10	0	4	2
Prionospio steenstrupi M	0	0	0	0	0	0	4
Terebellidae	1	15	2	5	1	7	4
Pista cristata (MU)	6	0	0	0	0	0	16
Thelepus setosus (Q)	0	0	0	1	0	0	0
Terebillides stroemi S	0	0	0	0	0	0	0
Shistomeringos longicornis (E)	0	0	0	1	0	0	0
Glycera capitata O	1	0	0	0	0	1	0
Goniadidae	0	0	0	0	0	0	0
Glycinde sp.	0	0	0	1	0	0	0
Glycinde picta B	2	0	0	10	0	0	2
Goniada maculata O	0	0	0	0	0	1	0
Lumbrineris sp.	12	2	8	4	1	2	32
Lumbrineris cruzensis H	2	1	3	3	0	0	2
Lumbrineris luti BB	15	10	15	32	6	57	30
Nephtys sp.	0	1	1	4	0	1	1
Neris sp.	1	0	0	0	0	0	0
Nothria conchylega (S)	0	0	0	0	0	0	0
Eteone longa (F)	0	0	0	0	0	0	0
Eulalia sp.	0	0	0	0	0	0	0
Phyllodoce sp.	1	0	0	0	0	1	0
Polynoidae	0	0	0	0	0	0	1
Harmothoe imbricata (L)	0	0	1	0	1	0	1
Pholoides aspera (J)	0	0	0	0	0	0	0
Sphaerosyllis brandhorsti HS	0	0	0	0	0	1	0
Ampelisca pugetica ST	0	0	0	5	0	0	2
Byblis sp.	1	1	1	1	0	0	1
Protomedia articulata BA	0	1	0	1	0	0	3
Photis sp.	0	0	0	0	0	0	1
Corophium sp.	0	0	0	0	0	0	0
Jassa sp.	0	0	0	0	0	0	0
Podoceridae	0	0	0	0	0	0	0
Dexamonica reductans BA	0	0	0	0	0	0	0
Monoculodes sp.	0	0	0	0	0	0	2
Synchelidium shoemakeri MI	0	0	1	0	0	0	0
Westwoodilla caeclua BT	0	0	0	0	0	0	1
Ostracoda	0	0	0	1	0	0	0
Cumacea	0	4	2	1	0	0	2
Alvania compacta C	0	15	23	25	0	0	7
Amphissa columbiana D	1	0	0	0	0	0	0
Mitrella sp.	0	0	0	0	0	0	6
Nitidella gouldi (C)	0	0	0	0	0	0	0
Nassarius mendicus (G)	4	0	0	0	0	1	1
Opithobranchia	0	0	0	0	0	0	0
Pelecypoda -juveniles	0	40	10	25	0	4	3
Clinocardium cf. fucanum (D)	0	0	0	0	0	0	0
Cardiomya californica (D)	0	0	0	0	0	1	1
Axinopsida serricata (C)	1	0	0	0	0	1	1
Protothaca staminea (CO)	0	0	0	0	0	0	0
Psephidia lordi (BI)	3	2	1	1	0	0	2
Anthozoa	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0

APPENDIX 7

TAXA FOUND EXCLUSIVELY IN TAILING OR CONTROL ARTIFICIAL SUBSTRATE CONTAINERS.

Taxa Found Only in Tailing Artificial Substrates		Taxa Found Only in Control Artificial Substrates	
Taxa	Total # of Individuals	Taxa	Total # of Individuals
Terebellides stroemi	1	*Pherusa plumosa*	1
Nemertinea	4	*Magelona sp.*	1
Opisthobranchia	1	*Schistomeringos longicornis*	2
Oligochaeta	1	*Nevis sp.*	1
		Nothria conchylega	1
		Eteone longa	1
		Eulalia sp.	1
		Pholoides aspera	1
		Jassa sp.	6
		Anthozoa	1
		Amphissa columbiana	1
		Holothuroidea	1

APPENDIX 8

NUMBERS OF POLYCHAETES, AMPHIPODS, GASTROPODS, PELECYPODS, AND OTHER TAXA IN ARTIFICIAL SUBSTRATES.

Values are means from two replicate artificial substrates
except where a replicate was lost then n=1.
See table 1 for artificial substrate codes.

	Mean Numbers /600 cm^2				
Artificial Substrate	Polychaetes	Amphipods	Gastropods	Pelecypods	Other Taxa
T1J1-A	7.5	18.5	1.5	0.0	2.5
C1J1-A	53.0	37.0	9.0	1.0	3.5
T2A-O	21.0	28.5	20.5	1.5	4.5
C2A-O	45.5	24.5	27.0	1.0	2.0
T2O-D	2.5	4.0	4.5	0.0	0.0
T2D-F	1.5	0.0	0.0	0.0	0.0
C2D-F	5.5	0.0	1.0	2.5	0.0
T2F-Ap	4.0	0.0	2.0	0.5	0.5
C2F-Ap	16.0	5.0	0.0	6.5	0.2
T2Ap-J	15.5	4.5	3.5	7.5	3.5
C2Ap-J	60.5	4.0	3.0	3.5	0.5
T2J-A	23.5	7.5	2.5	0.5	1.5
C2J-A	106.5	10.5	1.0	3.5	1.5
T4A-D	51.0	14.0	5.0	4.5	0.5
C4A-D	63.0	5.0	20.0	5.0	0.0
T4D-Ap	2.0	0.0	5.0	0.5	0.0
C4D-Ap	97.5	5.0	3.5	8.5	6.5
T4F-J	19.5	1.5	5.5	2.0	0.5
C4F-J	81.5	2.0	3.0	6.5	0.5
T4Ap-A	57.0	1.0	1.0	4.0	1.0
C4Ap-A	65.5	1.0	4.5	3.0	0.0
T8A-Ap	46.5	2.0	19.0	26.5	3.0
C8A-Ap	116.0	7.0	25.0	26.0	2.0
T8O-J	11.0	0.0	0.0	0.0	0.0
C8O-J	114.0	0.0	1.0	0.6	0.0
T12A-A	190.0	10.0	15.0	7.0	2.0

Publications:

Ellis, D.V. and Taylor, L.A. In Press. Biological engineering of aquatic mine tailing deposits. In: Salomons,W. and Foerstner (eds.) Impact and Management of Mine Tailing and Dredged Materials. Springer-Verlag, Berlin.

Taylor, L.A. 1984. Marine reclamation: recovery of the sea floor community following mine tailing discharge. In: Preceedings of the Eighth Annual British Columbia Mine Reclamation Symposium. Victoria, British Columbia. p 63-69

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Title of Thesis

Marine Macrobenthic Colonization of Mine Tailing in Rupert
Inlet, British Columbia.

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July 25, 1986
Date